METALLURGIA

THE BRITISH JOURNAL OF METALS

APR 3 1940

METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

PRINCIPAL CONTENTS IN THIS ISSUE:

Bells and Cannon

By Ernest Morris, F.R.Hist.S.

There would seem to be no connection between these emblems of peace and war, but since the early use of cannon they have been intimately associated as the author of this article shows.

A 15th Century Bury Bellfounder's Escutcheon.

BELLS and cannon—these two subjects seem very contradictory—the first being usually associated with the life and call of the Church, the other often is the herald of death and destruction. Far removed though they may seem, yet often have they been intimately connected.

Bells have frequently been taken as spoils of war, mostly to be broken up and used in making cannon and other munitions. Many instances of this could be quoted, one of the most famous being during the last Great European War (1914-18), when the Austrian Government consigned to the melting pot the great bell of St. Stephen's Church, Vienna. This bell had been cast in the year 1710 at the command of Emperor Joseph I, from the metal of 180 cannon captured from the Turks, and weighed nearly 18 tons. Another great bell, cast from French cannon captured during the Franco-German war, and weighing over 25 tons, was placed in Cologne Cathedral in 1874, and called the "Kaiserglocke." This was removed during the Great War (1914-18) and melted down for munitions to be used against the French, even as it itself had been originally mainly cast from French cannon. In 1925, however, a new bell was placed in Cologne Cathedral to replace the last-named, and of about the same weight. In the earlier part of the same war, the Russians removed many hundred

An old print (dated 1698) showing the association of cannon with bellfounders.

bells from the war area, and it is well known that both in Belgium and France many churches suffered the loss of their bells.

At Liversedge, Yorkshire, there is a complete ring of eight bells cast from cannon, and the inscription on one of them states :—

"These eight bells were cast in 1814 and 1815, with brass ordnance taken at Genoa."

Another episode of the Great War was when the Germans removed many bells from the churches of South Jutland, and to replace them in 1925 an order was given for 44 bells to be cast from the metal of 60 old brass cannon supplied by the Copenhagen Arsenal. At Roverto, Italy, is a bell known as the "Death Bell," and this was cast from metal from the guns of all nations who participated in the war. It is rung nightly in honour of the dead.

Our English mediæval bellfounders, too, did not always merely follow the craft of turning out bells only, for in those days they were not so much in demand as in later times. The founders, therefore, cast pots, lavers, mortars, and even guns. Bell-metal is very similar to what was known as gun-metal before the invention of ordnance, first of cast iron, then, as we have it to-day, of steel. In Henry VIII's time the exportation of bells and bell-metal became a criminal offence. An Act was passed which read : "Noe p'son or p'sons shoulde from henceforthe carrye or convey any brasse, copper, laten, bellmettall, gunemettall, ne shroffe metall into anye part or parts beyonde the sea upon payne of forfeyture of the said mettall." It is possible that the object of this law was to prevent bell-metal being purchased by unfriendly foreign powers, who might convert it into ordnance to be used against us. There was, of course, huge quantities of bell-metal for disposal after the dissolution of the monasteries about this time.

The Bury Bellfounders of the 15th century used as their foundry mark, which passed on to successive proprietors, an elaborate shield bearing a crowned bell, the keys of St. Peter, the crossed arrows, symbolic of St. Edmund (St. Edmundsbury) and a cannon with ball. In addition are the letters "H.S."—initials of the first founder there who combined the crafts of gunfounding with that of bell-founding. Similarly, other bellfounders did the same during this period. An instance of this is shown by the activities of Robert Mot, who founded the now famous Whitechapel Bellfoundry as long ago as 1570, in that he cast cannon for Queen Elizabeth's ships of war, at the time of the Spanish
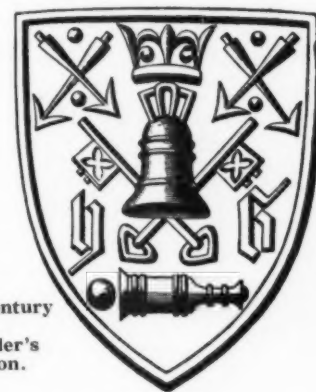
Armada. We have an instance of a bellfounder who was unfortunately killed while casting cannon. This was Matthew Bagley, one of a famous family of bellfounders of Northamptonshire, who, migrating to London, acquired the Royal foundry of Philip Wightman. The tragic manner in which he lost his life is thus described in the *Flying Post* of May 12, 1716 :—

> " Last Thursday night about nine o'clock a tragical accident happened at the Royal Foundry near Upper Moorfields, where, when the workmen were casting a cannon, the metal that was running into the mould flew up on a sudden with great noise and violence, and came down like drops of fire, not only upon all the workmen, but spectators (of whom there was a great number to see the performance). Several attended from the Tower, particularly Mr. Hall, Clerk of the Ordnance, who was so sorely wounded that he dyed next morning. The Master Founder and his son with above twenty others were also very much hurt. 'Tis generally agreed that the said accident was owing to the dampness of the mould."

The *Weekly Journal* of the same day further states that " Bagley, the master founder, has lost his eyes, and his son and sixteen others are desperately wounded." Both father and son died of their injuries as the register of St. Giles' Church, Cripplegate, shows :—

> " 1716. May 22. Matthew Bagley, Founder, killed.
> „ 26. Matthew Bagley, Jun., killed."

The accompanying copies of two old prints dated 1698 show bellfounders in the act of casting cannon. As with other foundries and similar works, during the last Great War, our bellfounders converted their works into munition factories, and to-day they are doing similar war work, and, in addition, turning out thousands of handbells for the A.R.P.

Creep of Some Chromium-Molybdenum Steels

In the development of steels for high-temperature applications, it is generally recognised that certain of the carbide-forming elements, such as chromium, molybdenum, and vanadium are the most effective in improving the strength characteristics. In certain of the chromium-molybdenum steels creep strength is only fair, and in this article are given the results of an investigation on the creep properties of 5% chromium, 1–1.5% molybdenum steel.

IN the oil-refining industry and for use with superheated steam, tubes made of 5% chromium, 0·45 to 0·65% molybdenum steel are widely used. Material of this composition has satisfactory corrosion and oxidation resisting properties, but its creep strength is only fair, with the result that excessively heavy tube walls are necessary in the higher pressure installations. As higher creep properties would be of advantage, particularly in the oil industry, a co-operative investigation has been carried out in the United States, to determine the high temperature creep properties of 5% chromium, 1 to 1·5 molybdenum steel, in order to ascertain whether the increased molybdenum content provides any improvement in such properties. A report on this investigation has been prepared by H. D. Newell,* and an adaptation of it has been published in a recent issue of *Metals and Alloys*.

Tests were carried out on two steels, one containing 0·114% carbon, 0·32% manganese, 0·73% silicon, 5·17% chromium, and 0·98% molybdenum, and the other 0·078% carbon, 0·25% manganese, 0·87% silicon, 5·24% chromium, and 1·50% molybdenum. In both steels the silicon content was high in order to increase oxidation resistance. The McQuaid-Ehn grain size of the two steels was similar at 7·8, and the Brinell hardnesses 161 and 160 respectively. Microscopic examination showed the lower molybdenum steel to have the somewhat finer structure. Both steels were annealed at 857° C. for three-quarters of an hour, and then cooled at the rate of 5° C. per hour to 730° C. before final cooling in the furnace.

Creep tests made at Massachusetts Institute of Technology included initial and final elongations, actual creep in inches per inch, rate of creep at certain intervals, and final rate of creep. Final creep rates were plotted to logarithmic co-ordinates and from these stress values for creep rates of 0·01 and 0·10% per 1,000 hours obtained. Average test results are given in Table I.

TABLE I.

Steel.	Rate per 1,000 Hours.	Temperature, °C.		
		540	595.	650.
5·17% Cr, 0·98% Mo......	0·01%	6,400	3,100	1,800
	0·10%	9,700	5,900	3,500
5·24% Cr, 1·60% Mo......	0·01%	6,400	3,250	1,380
	0·10%	11,300	6,400	3,050

*Metals and Alloys, 1939, Vol. 10, No. 11, pp. 342-345.

For comparison with these values, data for 5% chromium steels containing 0·05% molybdenum, and for two 2% chromium steels containing 0·5 and 1·0% of molybdenum respectively are given in Table II.

TABLE II.

Steel.	Rate per 1,000 Hours.	Temperature, °C.		
		540.	595.	650.
5% Cr, 0·50% Mo.	0·01%	7,200–7,600	2,400–3,200	900–1,700
	0·10%	9,200–10,250	4,200–6,000	1,800–3,300
2% Cr, 0·50% Mo.	0·01%	6,300	3,325	1,075
	0·10%	11,000	5,875	3,400
2% Cr, 1·0% Mo.	0·01%	7,600	4,910	2,510
	0·10%	16,350	9,200	4,175

When the creep values obtained from these various steels are considered, it is seen that increase of molybdenum from 0·5 to 1·0% in steel containing 2% chromium produces a decided improvement in creep-strength properties. This possibly results from the fact that such steel is of a pearlitic character due to its low alloy content, that it can be made of a coarse grain type resistant to plastic flow, and that increase in molybdenum tends towards increased resistance to spheroidisation and coalescence of the carbides under temperature.

Steel containing 5% chromium, however, is naturally cementitic, so that carbides spheroidise rapidly on annealing. Grain size in steel of this type is, in general, small, and it is difficult to effect much change in this property irrespective of melting practice. Attempts to coarsen structure by thermal treatments to improve creep properties detract from the effectiveness of molybdenum in suppressing temper brittleness, and lead also to reduced ductility and toughness. In consequence, any improvement in creep properties from additional molybdenum in 5% chromium steel must come mainly from a stiffening of the ferrite matrix with but slight benefit from the molybdenum combining with the carbide to produce a more stable form. A study, therefore, of the results in Tables I and II shows little significant advantage for high molybdenum contents over the standard 0·5% molybdenum for the temperature range dealt with. There is, no doubt, a slightly better resistance to creep in the 1 and 1·5% molybdenum steels at 595° and 650° C., but there is not sufficient difference in stress values to justify the increased cost of the addition over the usual 0·5% molybdenum addition.

Instrument Unit-Springs

By Richard Saxton

The author discusses briefly the design of instrument springs and the various forms used. Attention is directed to some aspects of their production, particularly to the need of confining hysteresis.

THE part played by the spring as a unit in most measuring and time-recording instruments is, apart from the spring trade interested, apparently little recognised. Instrument spring manufacture is what is known as a specialised operation, and is, in general, only undertaken by makers specialising in this particular product.

Designing of instrument springs is also a highly specialised branch of engineering, but in many instances design of spring is one of the last matters to be considered. Room or space for spring to function is usually assigned by guesswork, often resulting, when other components have been assembled, in curtailment of spring efficiency, due to limits to which it is confined. Efficiency and life of any spring is governed by the maximum value and range of stress in service, and if value is limited by compression in space insufficient for efficient performance, its value as a useful unit is definitely limited.

The bulk of instrument springs are produced from suitable metals fabricated into cylindrical wire, the flat type being cold-rolled from cylindrical material to shape and size desired. In all forms of production—spiral, helical, flat, etc.—a knowledge of the spring properties of the metal, stress imparted by various degrees of temper, and reaction to hysteresis is essential.

Springs in spiral form are employed chiefly in electrical instruments: helical, of the extension type, in spring balances, and elliptic in measuring instruments in which the dial is calibrated to suit the individual spring. Flat springs find a wide use as units in small-scale balances as used in many forms of retail business. Springs employed as units in electrical measuring instruments are, in general, required to meet specifications not usually essential in other types of instrument springs. Chief of these may be stated to be—material to be non-magnetic ; low electrical resistance : temperature coefficient of resistance to be as near zero as possible.

Elastic modulus change in the spring metal due to temperature changes is usually compensated by temperature affects in other parts of the instrument. In D.C. instruments fitted with permanent magnets, decrease of magnetic strength with increasing temperature usually offsets any decrease in strength of spring, nett change being hardly appreciable.

A factor not to be overlooked in the fabrication of practically all qualities of spiral springs is the tendency to uncoil on forming. This type of spring as an instrument unit is usually produced by cold-forming followed by heat-treatment, amount or degree of uncoiling being dependant on time and temperature of the heat operation. The tendency to uncoil does not always cease on cooling to atmospheric temperature ; numerous cases exist where it has continued after instrument assembly, with resultant variation in zero reading and calibration. Where reaction to heat-treatment in the spring form is known, the tendency to uncoil can be controlled and kept within fine limits.

Improvements in the heat-treatment of metals have led to a decided change in this form of spring processing, with resultant higher quality of finished product. Factors of importance in the change have been the pyrometer and microscopic examination, the former enabling a constant temperature to be maintained during heat-treatment, and the latter revealing that certain characteristics of grain formation produced by heat-treating are definitely associated with spring properties.

To meet electrical requirements, springs for electrical measuring instruments are usually fabricated from an alloy of copper. Spring properties are imparted by the cold-working in wire fabrication, followed by heat-treatment. Flat spring material is produced, as previously stated, by cold-rolling from the cylindrical wire form. After spring-forming this material is heated to 325° C. and held at this temperature from 20 to 30 mins.

Though the majority of springs fabricated from wire are cold-formed, methods of heat-treating during forming have been the subject of test and experiment, and it has been found that by raising to as high a temperature as possible, within the softening temperature of the metal, during forming, hysteresis is reduced to the minimum.

Compression springs are usually " set " after forming and heat-treating, this operation leading to a slight decrease in free length. In any subsequent operation the spring will rarely take further set, and will always return to the original free length under normal compression. In the majority of helical compression springs the stress under normal static conditions is evenly distributed throughout the free coils, exception being valve springs of constant pitch and coil diameter fabricated as units of high-speed engines. Recent experiments indicate that when the ends are squared and ground there is a better distribution of stress if the ends are positioned to make total number of coils slightly greater than an even number, as against fabricating with the ends in a direct line parallel to the spring's axis.

Helical compression springs with numerous coils are unsuitable as units for force-measuring instruments, the tendency to buckle under compressive stress being the chief fault. When a helical spring is deflected there is a gradual closing of the ends before contact is made between those adjacent in centre part of spring. It is this characteristic which makes long or numerous coil fabrications unsuitable for many services in which, otherwise, length would be an asset.

Earlier, mention was made of hysteresis, a serious form of defect. With scale springs efficiently designed and fabrication controlled during processing, it is possible to confine hysteresis to below one-tenth of 1%. Test for hysteresis consists in first loading spring to half capacity, measuring extension under load, then loading to capacity, followed by return to half load, extension again being measured and compared with first test.

As the difference representing the hysteresis loop is in general very small, usually only a few thousandths of an inch, measurements must be accurate and carefully made. Though possible to perform by several methods, the measurements are usually taken with a screw micrometer, complete with vernier reading to 0·0001 in., suitable attachments for making electrical contact being also included.

Minimum vibration under test is essential, and is attained by various means, each producer employing what he considers the best method to suit the particular size of spring under test. General practice with spring balances is to measure for hysteresis in the completed balance, by what is known as the " back test." This is performed by first loading to capacity with known increments of loading followed by unloading, each increment being loaded and unloaded separately and the difference noted. Any inaccuracy is easily noted and measured, and, if exceeding tolerances fixed as standard, result in condemnation of balance as unsuitable.

Correspondence

A Modern Cast-Iron—Meehanite

The Editor, METALLURGIA.

Dear Sir,

In your January issue there is an article on Meehanite, by Mr. E. M. Currie, which calls for some comment.

Table I, on page 65, appears to be almost an exact copy of data published in America fully six years ago, and it is unfortunate that the opportunity has not been taken to rectify what appear to the writer to be misleading figures.

A transverse test on cast steel is included, and the deflection is given as 0·2 in. Is it to be understood that the transverse bar actually broke at the load given, and with only 0·2 in. deflection? If it did it must have been an abnormally poor bit of cast steel.

In the same table the tensile strength of cast iron and semi-steel is given as 9 to 13 tons per square inch. It is scarcely doing justice to bodies such as the I.B.F. and the B.C.I.R.A. if such figures are to be accepted as typical of modern cast iron.

Mr. Currie must surely be aware that specifications calling for higher figures than these are being met every day. Among such may be mentioned the Admiralty grade for steam cylinders and pistons (15 tons per square inch on 1·2-inch diameter bar), and B.S.S. 821 gears and gear blanks, section 3, as-cast (15 tons per square inch on 1·2-inch diameter bar).

Mr. Currie devotes considerable space to questions of brittleness and toughness. Speaking of modern cast iron, at the foot of the first column on page 63, he makes the very sweeping statement, "It is a cast iron that is not brittle and which can easily be modified to suit exactly each and every service condition demanded of it."

Perhaps the writer might be allowed to quote the following from a short note which he wrote on high-duty cast iron (*F.T.J.*, December 15, 1938): "In considering the applications of high-strength irons, it is well to bear in mind that, although the tensile strength and impact resistance are greater than in the older types of iron, the material is still cast iron and has no measurable ductility. It contains graphite, and although it may be in smaller flakes yet the iron will not bend appreciably."

The writer suggests that the following table is a fair representation of the properties of various cast irons and cast steel :—

—	Tensile Strength, Guaranteed Minima.	Elongation.	Bend Test on 1-in. Dia. Bar.	Izod Impact, Standard Notched Bar.
	Tons per Sq. In.			
Cast iron	9–16	under 1%	under 5°	under 1 ft.-lb.
High-duty cast iron	16–20	,,	,,	,,
Meehanite (various grades) ..	13·5–22·5	,,	,,	,,
Cast steel properly annealed	26–35	over 15%	over 60°	over 15 ft.-lbs.

Yours faithfully,

J. ARNOTT.

The Laboratory,
   G. and J. Weir, Ltd.,
      Glasgow, S 4.
February 16, 1940.

The Editor, METALLURGIA.

Dear Sir,

I have read Mr. Arnott's comments on my article, "A Modern Cast Iron—Meehanite," which appeared in the January issue of METALLURGIA, with some interest.

It rather appears that Mr. Arnott has missed the whole purport of this article, which is to bring to the notice of the engineers the fact there exists to-day types of dependable engineering materials with known characteristics in the cast-iron range classified rather loosely at the moment as "high test irons."

These irons are not altogether new, and for the past twenty years intense activity in the foundry world, the I.B.F., the B.C.I.R.A., and many other research bodies has resulted literally in hundreds of methods being evolved, all with the purpose of improving what has been condemned formerly as an unreliable material—cast iron. That is the reason for new and more *exact* specifications being written every day. Study of all recent specifications shows that a considerable tightening up of demand is occurring, with the aim of securing *greater consistency and uniformity* of physical and mechanical properties each and every day with minimum variation of properties.

This is as it should be. Foundrymen are conscious of this ideal at all times and are working steadily towards it.

Mr. Arnott queries the tensile strength of cast iron and semi-steels as given in Table I, and suggests an even wider range of 9 to 16 tons per square inch. Even Mr. Arnott will agree that cast iron, as produced to-day by many foundries, has even a still wider variation of strengths than those given by him, and that is the crux of the trouble in the use of cast iron as such. Engineers need definite and known properties from individually processed irons. Table I, as stated, gives the *minimum guaranteed* general engineering physical properties of Meehanite which were *standardised*, as Mr. Arnott points out, over six years ago. Of what use to publish the fact that one or two Meehanite licensees making a speciality of process "A," for example, to-day could offer and guarantee tensile strengths of 30 tons per square inch (1 ton per square inch) in the "as-cast" state and 42 tons per square inch (2 tons per square inch) heat-treated unless all the foundries would be able to give this guarantee also?

I do not disagree with Mr. Arnott's table of physical properties. As it stands, however, it is useless as information to an engineer, and particular exception can be taken to the use of the standard izod impact notched bar for use with cast iron, and as a comparison figure with steel does not mean anything. Mr. Arnott should be aware that there is as yet no standard recognised impact test for cast iron, and that the usual izod test bar has been condemned by competent authorities for use on cast irons.

The common aim of metallurgists, engineers and designers, and all who use cast iron is to prevent, if at all possible, the continued thinking that cast iron will always be "unreliable" as evidenced by wide variations in physical properties obtained, due to loose and uncontrolled methods of manufacture. Such methods to-day are harmful and totally unnecessary. Modern cast irons, made under metallurgical knowledge and supervision, is lifting ordinary grey iron into the realms of a definite metal that can be specified exactly and used as a dependable construction material.

The designing engineer, with all his knowledge of materials and their behaviour, has no satisfactory system of choice of working stresses. There appears to be four important factors which affect this choice :—

1. The accuracy of the formulæ he uses for calculating purposes.
2. Dimensions of the members in the construction.
3. Estimation of the forces acting.
4. Physical characteristics of the material used.

No speculation is permissible, and he rightly demands from foundrymen definite basic data in order to answer factor No. 4 which, when all is said and done, is probably the most important, but the least understood. It is the erratic data on ordinary cast iron that destroys the confidence on which design is based. Uniform and consistent physical property data is necessary, and the iron foundryman who can obtain this is doing his job correctly.

E. M. CURRIE.

66, Victoria Street,
   London, S.W. 1.
February 28, 1940.

The British Machine-Tool Industry

FOLLOWING the last war the British machine-tool industry experienced what was probably the most disastrous period it has ever known. During the time of that war, as during the present hostilities, the industry was called upon to meet abnormal demands for machine tools to facilitate the production of machines, guns and shells for the Naval, Field and Air Forces. At the conclusion of hostilities many orders for machine tools then in hand, and some nearing completion, were cancelled, while thousands of machines which had been used on armament work were thrown on the market and sold by merchants at ridiculous prices. It is not surprising that this crude method of dealing with the surplus second-hand machines had the effect of crippling the industry, and for a period of at least ten years it was in a condition bordering on ruin. So bad were the conditions then prevailing that only those firms with extensive reserves were able to live through the disastrous period. The industry is again experiencing abnormal conditions of prosperity from a similar cause and, naturally, many are giving a thought to the future, and probably expressing the hope that the Government will bear in mind the ruinous conditions in the industry following the last war and will take steps to prevent second-hand machines contributing to similar conditions again.

Despite the difficulties experienced after the war of 1914-1918, there can be no doubt that the advance in British machine-tool design and production capacity since 1918 is enormous. Those who remember the Machine-Tool Exhibition, held in the Grand and Empire halls of Olympia, November, 1934, will appreciate the progress then made. That exhibition provided an opportunity for comparisons with American, German and Swiss machine tools, and it showed that British machine-tool design had caught right up with anything that could be done in competitive countries, while in some special types British machines were well ahead ; it was only in one or two types that foreign competitors had anything better to show. To-day there is no doubt that British machine-tool makers have continued to progress, and although certain firms in many of the machine-tool manufacturing countries remain predominant in the particular special machines of their own design, for the general class of machine tool there is no need to go outside of Britain, whether special high-production machines are required or those best suited for general jobbing work.

But a few large firms in this country still appear to have some sort of inferiority complex regarding British machines, and paradoxical as it may seem, some of these firms, with respect to their own manufactures, were very pressing on the public to buy British and contributed in no small degree to the national campaign launched under that heading. Those who have had the privilege of visiting American and German machine shops, as well as a number of British machine shops, will have noted that while British machine tools are very few in American and German shops, quite a reasonable proportion of the machines in British shops, notably those engaged in mass production, are of foreign manufacture. To some extent this peculiar position was understandable during the early

years following the last war, because the British machine-tool designer was seriously handicapped in his evolution of machine tools by the fact that his opportunities, compared with those of Americans and Germans, were seriously limited. But during the last eight or ten years the progress of British machine tools should have been sufficient to greatly reduce the proportion of foreign machine tools in the machine shops of this country.

Some figures on this aspect of the machine-tool industry will be interesting, since few probably realise the proportion of foreign machine tools which find their way into this country's machine shops. It is, of course, impossible to give accurate information under present conditions ; in any case it would be useless for purposes of comparison, because at the present time many British machine tool-makers cannot promise delivery on new orders inside one or even two years, and as a result American imports of these machines tend to increase. It is, therefore, preferable to give figures for 1938 as being the nearest to pre-war conditions. In the year 1938 the production of machine tools in this country was estimated at approximately £10 million. Official figures are not available as the last census of production figures related to a period some years previous. Some authorities put the figure for 1938 higher than £10 million, but apparently this figure may be regarded as a reasonable approximation. But exports of machine tools during this period were valued at £4,476,436, indicating that the remainder, valued at a little over £5½ million, were absorbed by the machine shops in this country ; during the same period, however, the value of machine tools imported reached £4,962,980. In other words, the value of foreign machine tools installed in British works during 1938 was almost equal to that of British machine tools installed.

It is not suggested that the competitive spirit between British and foreign manufacturers should be removed by the closing of the home market to foreign machines, but it should be realised that few of the British machine tools exported are installed in either the United States or Germany. Britain has sent a few, a very few, machines of certain types to these countries, but in each case the market is insignificant. In the States, years of high protective tariffs and unhindered development in the domestic market account for the absence of foreign machines in the United States. In her home market alone the scope for new development in machine tools is probably eight to ten times what it is in Britain, and there is not the same conservative prejudice against new departures, consequently both the necessary money and customers are forthcoming. These conditions have been responsible for building up the machine-tool industry in the United States on a much broader and sounder basis than has been possible in this country. In years past the same conditions helped the Germans to keep their works clear of imported machines, and during more recent years the policy of self-sufficiency of the so-called national socialism does the rest.

Mention has been made of the serious handicap of the British machine-tool engineer for many years after 1918 in the development of machine-tool design in comparison with those of Americans and Germans, and it will be of interest to consider briefly some of the factors that imposed serious limitations on British designers. First of all, as already mentioned, thousands of used machines were

thrown on the market, seriously reducing the market for new machines in this country ; for the very limited home market firms in competitive countries were able to compete with British makers on free and unfettered terms ; with a depleted home market British makers received no assistance from the Government in planning for export trade and the banks refused financial assistance ; practically every manufacturer was in a state of poverty for many years and could not find money for development on new machines or of markets abroad for his products. During this lean period of the British machine-tool industry makers in the United States, due to their bigger home market and the increase in mass production of her manufactures, were able to develop not only design but also markets abroad. German makers were in a similar position, and her exports of machine tools were greatly assisted by the scheme for the payment of reparations in kind and by barter arrangements. In addition, the import of machine tools from these countries has always been favoured by the prejudice that exists in this country to some extent in favour of foreign machines.

For these reasons the British machine tool-maker was lagging behind those of the United States and Germany from 1918 to about 1932. During this period American machine tools, in particular, certainly led in a very large number of machines of vital importance to manufacturers in this country, and purchasers became obsessed with the view that while British machines were all right for the usual general jobbing work, for real production it was necessary to get American machines. In 1932 tariffs were applied to all foreign machine tools, with the exception of those which were not being made in this country, and it was this policy and the courage and foresight of many makers which brought about the resuscitation of the British machine-tool industry and brought about a transformation that proved a revelation to engineers from all over the world who visited the 1934 exhibition. Even after tariffs were applied German machine tools were still freely imported, due to the liberal subsidies granted by the German Government to its machine tool-makers to render their effect negligible. This form of competition was one with which British machine tool-makers became well acquainted when selling on the Continental market. Despite these difficulties, however, the progress and advancement which had been made by British machine-tool makers by 1934 was of such a high order that since that time the prejudice in favour of foreign machines, though still existing, is not now so frequently heard expressed. Certainly, if war conditions are excluded, it is not now so common for a firm to pay considerably more for a foreign machine in preference to a British machine, which from every point of view is at least its equal.

Home and Overseas Markets for British Machine Tools

At the present time it is difficult to speculate on the extent to which the British machine-tool industry is meeting home requirements. Domestic conditions will, we fear, be upset for a considerable number of years to come by present conditions. It will be appreciated that current domestic requirements in machine tools are conditioned by the extent of our war effort, and at the same time the British machine-tool industry has to cater, to a large extent, not only for the home market but for the British Dominions and for France. This vast call upon the resources of the British machine-tool industry has inevitably brought about a certain measure of Government control, one of the chief features of which has been for the time being a complete severance of business with the neutral countries.

For these reasons it is not easy to discuss separately the extent to which the British machine-tool industry can contribute to the need for increasing this country's export trade. The output capacity of Britain for machine tools must have been doubled in recent years. Most makers have extended and new makers have appeared. It is our view that British makers can supply all the normal require ments of the country, and they can also supply a consider able part of the machine tools required in the various countries of the world. There is no doubt that with its present capacity the contribution of the British machine-tool industry to the export trade should be substantial, although after the present lapse of normal contacts with formerly profitable markets much leeway will have to be made up.

After-War Prospects

The machine-tool industry is a key industry in peace as in war times, and as such is of vital importance in providing the means for supplying everything which the general public find a necessity or a comfort ; it is a temptation, therefore, to ask what are the prospects for the British machine-tool industry on the conclusion of present hostilities ? The demands for war, unfortunately, have the result not only of stopping the export of a large number of machines which were going to markets overseas, but all the work of past years in building up connections in these markets. New connections in these foreign markets will have been opened with suppliers of other countries, and much work and time will be involved in restoring or making new contacts.

The industry is in a better position to-day than during the last war in that it is now more adequately represented by an effective trade association, and it has the bitter experience of the years following that war as a guide to what may happen in the future, unless the lessons of that period are now thoroughly understood and will be acted upon by those in authority. It seems to us that the industry should have impressed upon the Government the vital national importance of its work years ago. To-day, the Government is only realising the fact that the first step should have been made three or four years ago, when the rearmament programme was put into operation. Will the Government show the same anxiety when peace is restored ? We do not know, and therefore any reference to future prospects for the industry can only be conjecture. They will depend to a great extent on the recognition that modern machine tools are no less important in peace than in war in a competitive world where the rule of the survival of the fittest still holds when the conditions are approxi mately similar for each competitive firm.

But there is one aspect which will have a considerable influence on the prospects of the industry after the war, and it is not too early to give it serious thought. What will become of the thousands of machine tools installed or on order for war purposes ? A new orientation in the policy of obsolescence will be imperative if the industry is to be saved from the catastrophe it experienced in the years following the last war. Bearing in mind that the majority of these machines are in constant operation on a twenty-four-hour-day basis, the wear on them will be so severe that in many cases they could be regarded as having exceeded their useful life, in which case they should be scrapped and not reconditioned. In some cases the machines may be in too good a condition to warrant such drastic treatment, and a good policy would be for the Government to maintain nuclei of shadow factories with such plant.

Something must be done to prevent the surplus machines being bought up at ridiculous all-in prices by merchants, for them to subsequently flood the home market with reconditioned machines. In such a case history would repeat itself. Let the Government remove this possibility and the industry would have every incentive to develop new models and maintain the high standard it has now achieved, and it would be in a fair way to meet home requirements while being able to compete successfully with foreign makers in the machine-tool markets of the world.

The Brittle Phase in High Chromium Steels

By J. H. G. Monypenny, F.Inst.P.

The hard, brittle and non-magnetic constituent found in certain high chromium steels is discussed, and the work of many investigators on the structure of the alloys is reviewed. This constituent has been termed the sigma phase, and recently three important papers have been published dealing with the occurrence of this phase. In this article are described the results obtained by these latter investigations and their bearing on the practical use of the alloys. Iron-chromium-nickel and iron-chromium-manganese alloys are discussed.

SOME thirteen years ago, when investigating the structure and properties of iron-chromium-nickel alloys, Bain and Griffiths[1] found that if those which contained up to 25% nickel—the remainder being iron and chromium in about equal proportions—were annealed for long periods at 800° C. or thereabouts, a new constituent appeared in their microstructure. This constituent was hard, brittle and non-magnetic, and appeared to be formed, with a considerable diminution in volume, from the ferrite which the alloys contained after they had been cooled rapidly from 1,000° C. or over. They suggested that this " B-constituent," as they called it, consisted of the intermetallic compound FeCr, which apparently could dissolve a certain amount of excess iron or chromium and also a few per cent. of nickel. They found that it was the stable low temperature form of 50 : 50 iron-chromium alloys containing up to about 10% nickel. At high temperatures these alloys consisted of the body-centred alpha solid solution, and this was transformed completely to the " B-constituent " by prolonged annealing at 800° C. The alpha solid solution may, of course, be regarded as ferrite, with about half the iron atoms replaced by chromium and nickel. With higher contents of nickel—up to about 25%—the iron-chromium ratio remaining the same, the structure after cooling from high temperatures consisted of a mixture of this alpha solid solution and the face-centred gamma phase, which similarly may be looked upon as austenite with chromium and nickel atoms replacing some of the iron. When annealed in the same manner, the α phase in these alloys also changed to the brittle constituent, the γ phase remaining apparently unaffected.

At about the same time Chevenard[2] observed an irregularity in the expansion of iron-chromium alloys when the chromium content exceeded about 42%, and concluded that this was due to the formation of a compound.

Subsequently doubts were expressed as to whether the " B " constituent was actually the compound FeCr, and a further idea, that it might be due to nitrogen in the alloys, was put forward by Aborn and Bain in 1931.[3] It should be noted, however, that Bain and Griffiths had considered this possibility and had melted in a vacuum special charges consisting of electrolytic iron and chromium of exceptional purity in order to eliminate contamination with nitrogen and other possible impurities ; as the brittle constituent was also formed in these alloys, they considered that its production could not be dependent on the presence of nitrogen.

In 1931, Adcock[4] examined a series of iron-chromium alloys of exceptional purity, and failed to obtain evidence of the existence of any such compound ; he reported that alloys containing 48·8 and 50·5 atomic % of

chromium, which had been annealed for four days at 600° C., possessed the X-ray pattern of the alpha solid solution.

In the same year, however, confirmation of the formation of the brittle constituent in iron-chromium alloys—and also in certain iron-chromium-nickel alloys—was obtained by Wever and Jellinghaus.[5] These investigators noted its microstructural characteristics, hardness, brittleness, lack of ferro-magnetism, greater density than the α-phase from which it was formed, the sluggishness of this change and also of the re-formation of the α-phase at higher temperatures. They also tried to determine its crystal structure by X-ray analysis, and although the diffraction patterns obtained were too complex to permit them to calculate the crystal form without further investigation, they pointed out the similarity of these patterns to those given by the compound FeV, which they had previously found in iron-vanadium alloys, and considered that this similarity afforded definite proof that the iron-chromium constituent was the compound FeCr.

Wever and Jellinghaus also determined approximately the composition range in which the brittle constituent was produced in the binary iron-chromium alloys. At 600° C. they found it could exist as a single phase, while its chromium content varied from about 46 to 52 atoms %, thus confirming Bain and Griffiths' result that the compound could dissolve excess iron or chromium. As one component of a duplex structure, in equilibrium with the body-centred solid solution of iron and chromium (i.e., the α-phase) as the other component, it was produced at the same temperature over a range of composition which extended to 38–40% chromium on the iron side and to 57–60% on the chromium side. At 900° C. the composition limits within which the compound could be detected had contracted to such an extent (to about 46–50% Cr) that the authors considered the upper limit of stability of the compound could not be much above this temperature. In this connection it may be noted that Bain and Griffiths gave about 885° C. as the temperature at which the α-phase was re-formed in nickel-free alloys. This value, which was based on thermal curves, is only approximate, however, as the arrests on these curves were not very definite. These authors also noted that additions of nickel raised the temperature at which ferrite was re-formed—the value given for alloys with 10% or so nickel being 960° C. —and made the thermal arrests much more definite. Fig. 1 shows the Fe-Cr diagram, as drawn by Adcock,[4] but with lines added indicating the range of existence of the brittle constituent (marked σ) according to Wever and Jellinghaus.

More recently, Erikssen[6] investigated a part of the FeCr system by X-ray analysis and obtained unmistakable evidence of a new phase over a considerable range of composition. He suggested that the complex crystal

1 E. C. Bain and W. E. Griffiths. " An Introduction to the Iron-Nickel-Chromium Alloys." *Trans. Amer. Inst. Min. and Met. Eng.*, 1927.
2 P. Chevenard. " Travaux et Memoirs du Bureau International des Poids et Mesures." Vol. 17 (1927), p. 60.
3 R. H. Aborn and E. C. Bain. *Trans. A.S.S.T.*, September, 1930.
4 F. Adcock. *J.I.S.I.*, 1931, II, 99.

5 F. Wever and J. W. Jellinghaus. *Mitteil. Kaiser-Wilhelm-Inst. Eisenforschung.* Vol. 13 (1931), pp. 93 and 143.
6 S. Erikssen. *Jernkont. Ann.*, 1934. Vol. 88, pp. 530–543.

structure of this phase had a deformed cubic pattern with monoclinic or triclinic symmetry.
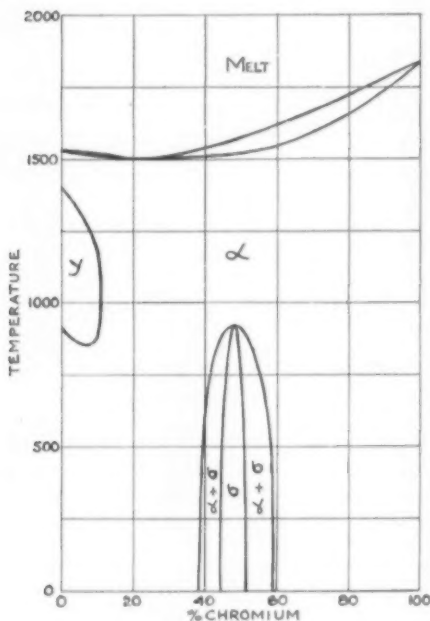

In August, 1936, an interesting article by E. R. Jette and F. Foote[7] threw some light on the conflicting results which had hitherto been reported as to the existence of this hard, brittle constituent, which, for convenience will be termed the sigma phase. An extensive investigation of the iron-chromium-silicon diagram by X-ray analysis, then in progress in the metallurgical laboratories at Columbia University, New York, had shown that

Fig. 1.—FeCr diagram with composition limits of sigma phase, according to Wever and Jellinghaus.

diffraction patterns, qualitatively similar to those reproduced by Wever and Jellinghaus, were given after appropriate heat-treatment by a number of these alloys whose composition extended over a wide range. Further exploration showed that these diffraction patterns were obtained at progressively lower silicon contents along the line in the ternary diagram, where the ratio of atom % chromium to atom % iron was unity ; the alloy with the least silicon contained only 0·087% of that metal. They remarked that the diffraction pattern of this phase was strikingly different from that of the alpha-iron phase, and also bore no resemblance to any known nitride, carbide, or oxide of iron or chromium.

As it appeared from the investigations on silicon-containing alloys that the formation of the sigma phase occurred more readily in the presence of this metal, Jette and Foote prepared two alloys (containing respectively 50·6 and 48·5 atomic % iron) from specially purified metals melted in vacuo to see whether the phase could be produced in practically silicon-free alloys. Samples of each of these alloys, whose silicon contents were only 0·003% and 0·006% respectively, were prepared by suitable heat-treatment in both the alpha and sigma conditions, and were then annealed for prolonged periods at various temperatures with the results in Table I.

These results indicate that the σ-phase is formed in alloys of high purity. On the other hand, as Adcock[4] had found that a similar alloy consisted solely of the alpha phase after annealing for four days at 600° C., an explanation for this differing behaviour was sought and was found in the accelerating effect of cold deformation on the change from the alpha to the sigma condition. Experiments on powder prepared from the alloy containing 50·6 atomic % of iron—referred to previously—showed that whereas this powder, which had been annealed for 30 mins. in vacuo at 1,000° C. to remove previous cold-work effects, contained only a trace of the sigma phase after annealing for 252 hours at 600° C., a similar sample which had been rubbed in an agate mortar after the 1,000° C. anneal was then almost wholly converted into the sigma phase by holding for 24

hours at 600° C. Even in this cold-worked condition, however, the conversion did not begin immediately ; after 4 hours at 600° C. the sample was strongly magnetic, indicating that it was still mainly in the alpha condition. These results provide a reasonable explanation why Adcock's samples showed no evidence of the presence of the sigma phase. Prior to being annealed for four days at 600° C., they had been given a vacuum anneal for 12 hours at 1,300°–1,350° C. to remove " coreing " ; being thus in an almost perfectly stress-free condition, they would be practically unaffected by the annealing at 600°. Filings were then prepared from the annealed blocks for X-ray analysis ; the subsequent re-heating of these for 30 mins. at 600° to remove cold-working effects before they were actually tested would not produce an appreciable precipitation of the sigma phase.

It follows, from the investigations of Jette and Foote, that—

(a) In pure FeCr alloys the transformation alpha—→ sigma is reversible at a temperature between 775° and 800° C. (a value much lower than those given by Bain and Griffiths or by Wever and Jellinghaus), and takes place very slowly in both directions.

(b) The rate of transformation is increased by the presence of silicon and by prior cold work.

Investigations on iron-chromium-manganese alloys by Brühl[8] and by Schmidt and Legat[9] also showed quite definitely that, with appropriate heat-treatment, an intensely hard, brittle, non-magnetic constituent is formed in such alloys within certain ranges of composition, and that manganese, like silicon, appears to increase quite markedly the ease with which this constituent is formed. It is obvious that if this hard phase is based on the compound FeCr, the latter must have the capacity of dissolving appreciable amounts of nickel, manganese and silicon, as well as excess iron or chromium. Isolated data have also been published on the embrittlement of certain complex heat-resisting steels—containing chromium, nickel and other alloys—which might well proceed from the formation of this sigma phase. On the other hand, no mention is made of the presence of a hard, brittle constituent in the account given by Jenkins and his co-workers at the National Physical Laboratory of their detailed investigations on the structure and properties of iron-chromium-nickel alloys,[10] in spite of the fact that they examined some containing up to 50% Cr which had been annealed at 800° C. It should be mentioned, however, that they did not subject their alloys to X-ray examination, and the detection of the sigma phase purely by microstructural observations is not always easy.

TABLE I.

Atomic Fe %.	Phases present before Annealing.	Annealing Temperature.	Time, Hours.	Phases present after Annealing.
48·5	Mostly σ	1,049° C.	18	α only
50·6	α	904°	18	,,
	σ	904°	18	,,
	α	800°	22	,,
,,	σ	800°	22	Some α, mostly σ
	α	775°	44	α + σ
,,	σ	774°	44	σ only
	α	756°	44	,,
,,	σ	756°	44	,,
48·5	Mostly σ	717°	141	Mostly σ, some α
48·5	α	716°	37	σ + trace α
48·5	α	710°	161	σ only
50·6	α	600°	48	,,

About two years ago a summary of what was known at that time regarding iron-chromium-manganese alloys was given in these columns by the present writer.[11] It was then shown that although the limits of composition within

7 E. R. Jette and F. Foote. *Metals and Alloys*. Vol. VII (1936), p. 207.

8 F. Brühl. *Archiv. f.d. Eisenhüttenw.* Vol. 10 (1936-37), p. 243.
9 Schmidt and Legat. *Archiv. f.d. Eisenhüttenw.* Vol. 10 (1936-37), p. 297.
10 Jenkins, Bucknall, Austin and Mellor. *J.I.S.I.*, 1937. Vol. II, p. 187.
11 " Chromium-Manganese Steels as Heat-resisting Steels." METALLURGIA, Nov., 1937, and January, 1938.

which the sigma phase could be formed by suitable annealing were not completely known, enough information was available to indicate that iron-chromium-manganese alloys suitable for commercial use as heat-resisting steels would lie within a very restricted range of composition. Since then three important papers dealing with the occurrence of the sigma phase—two in iron-chromium-manganese alloys and the third in iron-chromium-nickel—have been published. It is intended to describe in this article the results obtained by the authors of these papers and to indicate their bearing on the practical use of the alloys. As the nickel-containing alloys are the more important commercially, attention will be given first to these and afterwards to those with manganese as the ternary alloy.
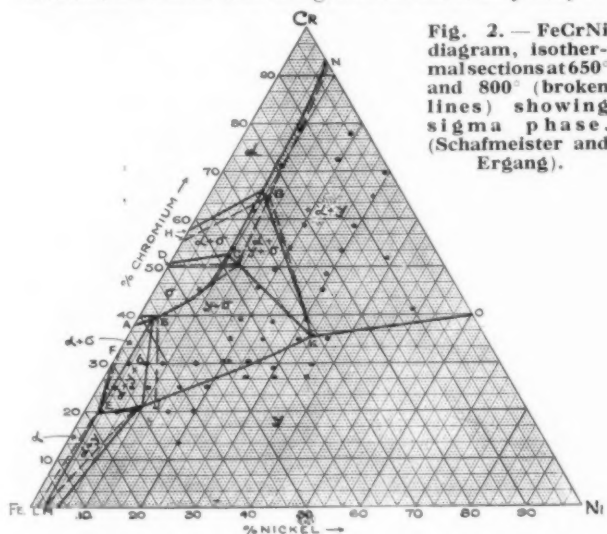
Fig. 2. — FeCrNi diagram, isothermal sections at 650° and 800° (broken lines) showing sigma phase. (Schafmeister and Ergang).

Iron-Chromium-Nickel Alloys

A comprehensive investigation on the constitution of these alloys, more particularly with regard to the range of composition in which the sigma phase may form, has been done in the research laboratories of Messrs. F. Krupp, A.-G., a detailed account being published in February, 1939, by Drs. Schafmeister and Ergang in the Krupp journal, *Technische Mitteilungen Krupp : Forschungsberichte*. The alloys investigated, numbering about 50, were made in a small high-frequency electric furnace, and contained between 20% and 80% chromium and between 3% and 50% nickel. They also contained as impurities up to 0·1% carbon, except in one case where it was 0·14%, about 0·4% manganese, and an average of about 0·3% silicon, though the highest chromium alloys contained more than
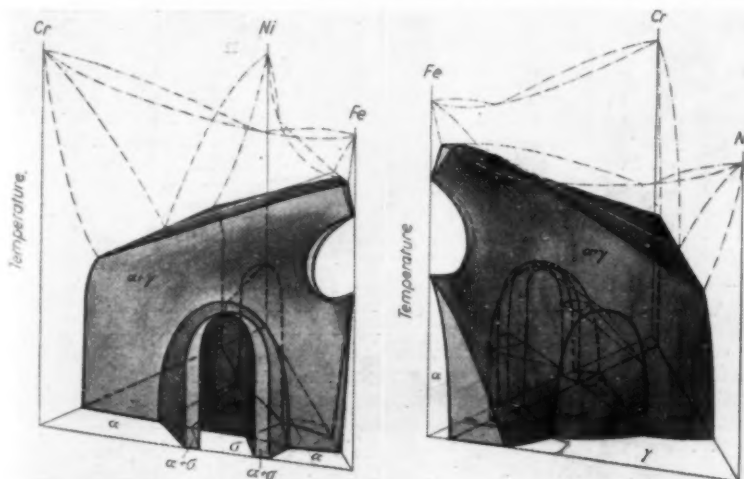
this, up to a maximum of 1·10%. The alloys were first annealed for 2 hours at 1,200° C. and then quenched in water. Their hardness and magnetic properties and their microstructure were determined in this condition, and also after subsequent annealing for 200 and 1,000 hours at 650° C. and for 200 hours at 800° C. The authors state that these very long annealing periods were necessary because the separation of the sigma phase occurs only very sluggishly in nickel-containing alloys.

As the sigma phase is hard and non-magnetic and is formed almost exclusively from the magnetic alpha phase, its appearance was shown by an increase in hardness and decrease in magnetic saturation. Some of the alloys were also examined by X-ray analysis when the indications of the other methods of test were somewhat doubtful. From the results of all the tests, coupled with data obtained by previous investigators, isothermal sections of the ternary model at 650° and 800° were drawn. The 650° section is shown in full lines in Fig. 2 ; where the 800° section differs it is shown in the broken lines. As there is not much difference between the two sections, it may be concluded that there will be little or no change below 650°. The dots in Fig. 2 represent the compositions of the alloys tested.

The rather complex " build-up " of these sections may, perhaps, be more easily understood from the diagrammatic spatial model shown in Figs. 3 and 4 and the diagram in Fig. 5, which is based on the results of Jenkins and his colleagues and represents structural conditions at 800° C. if the presence of the sigma phase is ignored. It should be noted that the spatial model does not give details of temperature and composition and is not necessarily drawn exactly to scale.

The range of stability of the sigma phase extends in tunnel fashion from the FeCr binary through the α and the $\alpha + \gamma$ fields (Fig. 5) and ends on the austenite face of the latter. The tunnel formation may be regarded as consisting of an inner tunnel enclosed in tunnel walls. The inner tunnel is a single-phase field of the σ-phase during the first part of its course, but becomes a duplex $\gamma + \sigma$ field when it enters the duplex $\alpha + \gamma$ field, which, apart from this intrusion of the " tunnel " formation, extends across the ternary diagram as indicated in Fig. 5. The " tunnel walls " in the first part of their course have a duplex $\alpha + \sigma$ structure, these duplex fields being each bounded in horizontal section by four lines, as shown in Fig. 2. Later, the walls become triple $\alpha + \gamma + \sigma$ fields, each with a triangular horizontal section. The thickness of the tunnel walls decreases towards the top of the tunnel and towards each end.

With this general idea of the effect of the σ-phase in mind, one may proceed to a detailed consideration of the isothermal sections. An inspection of Fig. 2 shows that Schafmeister and Ergang tested very few low-nickel alloys containing more than 30% chromium. Points D and H were taken from Wever and Jellinghaus[5]—who, it may be

Figs 3 and 4.—Spatial model of FeCrNi system.

Fig. 5.—FeCrNi diagram, section at 800° (Jenkins et alia).

TABLE II.
STRUCTURE, HARDNESS AND MAGNETIC PROPERTIES OF ALLOYS CONTAINING 20—30 CR.%

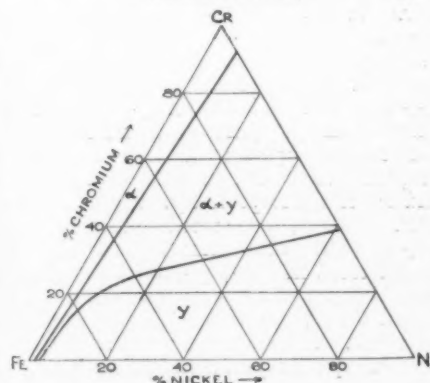| No.	Composition				2 hours 1,200° C., W.Q.			2 hours 1,200° C., W.Q., then (a) 200 hours 650° C., air-cooled. (b) 1,000 " "			2 hours 1,200° C., W.Q., then 200 hours 800° C., air-cooled.		
	C.	Si.	Cr.	Ni.	Structure.	Inductance Gauss.	Brinell No.	Structure.	Inductance Gauss.	Brinell No.	Structure.	Inductance Gauss.	Brinell No.
20/3	0·07	0·18	20·0	3·0	α + γ	14,470	207	α + γ + σ	(a) 14,900 (b) 14,650	(a) 208 (b) 214	α + γ + σ	15,000	228
20/6	0·14	0·30	19·7	6·0	α + γ	1,980	171	α + γ + σ	(a) 9,300 (b) 8,450	(a) 257 (b) 248	α + γ + σ	3,460	209
20/9	0·10	0·35	19·9	8·9	γ	26	143	γ	(a) 90 (b) 113	(a) 161 (b) 158	γ	44	146
20/15	0·10	0·35	19·9	14·9	γ	30	127	γ	(a) 28 (b) 36	(a) 141 (b) 141	γ	29	131
20/20	0·10	0·34	20·0	19·8	γ	35	116	γ	(a) 36 (b) 35	(a) 127 (b) 132	γ	36	122
25/3	0·04	0·23	25·0	2·96	α	13,500	215	α + σ	(a) 12,850 (b) 11,750	(a) 180 (b) 179	α + σ	11,890	176
25/6	0·04	0·30	24·9	6·0	α + γ	8,910	186	α + γ + σ	(a) 3,530 (b) 2,950	(a) 218 (b) 261	α + γ + σ	5,800	187
25/9	0·05	0·30	25·0	8·9	α + γ	5,130	170	γ + σ	(a) 85 (b) 40	(a) 230 (b) 231	α + γ + σ	2,037	180
25/15	0·10	0·33	25·1	14·7	α + γ	465	132	γ + σ	(a) 30 (b) 25	(a) 137 (b) 138	γ + σ	43	137
25/20	0·07	0·32	24·8	19·5	γ	26	119	γ	(a) 26 (b) 27	(a) 136 (b) 135	γ	26	121
30/3	0·05	0·31	30·2	3·0	α +(γ)	11,600	209	α + γ + σ	(a) 11,930 (b) 10,250	(a) 205 (b) 244	α + γ + σ	12,300	200
30/6	0·07	0·35	30·1	5·9	α + γ	11,000	210	α + γ + σ	(a) 2,440 (b) 222	(a) 396 (b) 458	α + γ + σ	8,170	213
30/9	0·08	0·34	30·1	8·8	α + γ	7,750	217	γ + σ	(a) 30 (b) 29	(a) 387 (b) 396	γ + σ	32	360
30/15	0·08	0·32	30·4	15·1	α + γ	3,390	186	γ + σ	(a) 34	(a) 249	γ + σ	90	279
30/20	0·07	0·40	30·2	19·9	α + γ	1,285	154	γ + σ	(a) 26	(a) 190	γ + σ	39	251
30/20A	0·035	0·20	30·2	20·7	α + γ	Weakly magnetic	162	γ + σ	Non-magnetic	(a) 182 (b) 191	γ + σ	Non-magnetic	190
30/25	0·033	0·21	30·4	24·3	(α)+ γ	Very weakly magnetic	140	γ +(σ)	"	(a) 149 (b) 143	γ +(σ)	"	153
30/30	0·03	0·13	28·8	29·5	γ	Non-magnetic	137	γ	"	(a) 135 (b) 123	γ	"	131
30/36	0·023	0·20	29·6	36·2	γ	"	134	γ	"	(a) 138 (b) 130	γ	"	148
27/25	0·03	0·09	27·1	25·5	γ	"	123	γ	"	(a) 129 (b) 128	γ	"	137
27/30	0·03	0·12	27·0	30·7	γ	"	125	γ	"	(a) 124 (b) 123	γ	"	136
27/35	0·03	0·17	27·1	36·7	γ	"	125	γ	"	(a) 137 (b) 130	γ	"	139

noted, determined these positions only approximately,—and points A and F from the later investigations of Burgess and Forgeng to which detailed consideration will be given in the section on manganese alloys. The sigma field includes only one alloy (45·4% Cr, 8% Ni), and hence the lines ABCD can only be regarded as giving a rough indication of the position of its boundaries. However, the point to be emphasised is that alloys whose composition lie approximately in this area consist of the α solid solution at high temperatures, and they are converted completely into the brittle σ-phase by prolonged annealing at temperatures between about 650° and 800°.

The position of the "tunnel wall" towards the iron corner of the diagram—i.e., the duplex field ABEF and the triple field BEJ—is founded mainly on the properties of the alloys containing 20–30% Cr, which are given in detail in Table II. Point F—the limit of the duplex α + σ field in the FeCr binary—is taken from the work of Burgess and Forgeng as mentioned previously. Lines FE and EJ appear to depend almost completely on the properties of the two 20% chromium steels containing 3% and 6% nickel respectively. These alloys, after quenching from 1,200° C., are stated to have a duplex structure of α + γ, which, after annealing at either 650° or 800° C., is converted into α + γ + σ, the sigma phase being presumably formed from some of the α solid solution. It is stated that there was microscopic evidence of the precipitation of the σ-phase; photomicrographs of the 6% nickel alloy are reproduced in the original memoir, but they are at too low a magnification to be very convincing. In the case of the 3% nickel alloy, the magnetic saturation value suggests that in the quenched form the steel consisted of ferrite and martensite, the latter resulting from the breakdown during quenching of the austenite formed at high temperatures. As the carbon content is very low, there is little change in either hardness or magnetic properties on annealing at 650° or 800° C. The 6% nickel alloy, however, contains twice as much carbon, and this fact, together with the higher nickel, would appear to account satisfactorily for the changes in magnetic and hardness values of this steel produced by different treatments. After quenching from 1,200°, the structure obviously consists mainly of retained austenite, together with some ferrite; the very marked increase in induced magnetism after annealing at 650° indicates the breakdown of the austenite with the formation of martensite, possessing also a higher Brinell hardness. Annealing at 800° has caused a partial re-formation of austenite with a consequent drop both in hardness and magnetic values. Hence the changes in properties of these steels after annealing are explainable, at least qualitatively, without recourse to the presence of the sigma phase. It would seem very desirable that there should be further investigation of alloys in this part of the ternary diagram before it is concluded that the range of stability of the sigma phase extends to quite so low a chromium content as 20%.

The alloy with 25% chromium and 2·96% nickel is stated in the original paper to consist of the alpha phase in

the quenched condition and of $\gamma + \sigma$ phases after annealing; the latter seems obviously a misprint for $a + \sigma$ and has been so altered in Table II. The slight fall in magnetic saturation after annealing would be in accordance with the formation of a small amount of the sigma phase, but the hardness values do not give any corroborative evidence. The 30% chromium alloy with 3% nickel is stated to consist of $a + (\gamma)$ as quenched and $a + \gamma + \sigma$ after annealing. The authors were obviously in doubt as to the presence of the gamma phase in the quenched condition—if it was not found in the 25% chromium alloy with similar nickel content, it is very unlikely to be present in that with 30% chromium,—and one may perhaps equally doubt its presence after annealing. However, there seems to be good evidence from hardness and magnetic data of a small precipitation of the sigma phase in this alloy, and hence it probably should be placed in the $a + \sigma$ field in both the 650° and 800° sections.

The 6% nickel alloys containing 25% or 30% chromium show definite evidence of sigma precipitation on annealing; there seems no doubt that the triple $a + \gamma + \sigma$ field includes both these alloys. Increasing the nickel to about 9% in the 25% chromium alloys leads to an interesting feature. After annealing at 650°, this sample is almost non-magnetic and obviously consists of $\gamma + \sigma$, the former being much in excess if one may judge from the hardness values. After annealing at 850°, however, the sample is markedly magnetic, due to the formation of some alpha phase, and also much softer. As the authors point out, the limiting surface of the $a + \gamma$ field—and hence the composition of the a and γ solid solutions—varies markedly with temperature in this region.

It follows from these results that even if one assumes that the line EJ in Fig. 2 is drawn at too low a chromium content, as was suggested might be the case, there seems no doubt that its position is definitely below 25% chromium.

The appreciable difference between the positions of BK at 650° and 800° indicates the effect of temperature on the $a + \gamma$ equilibrium. The position of this line—and, as a result, that of point B also—appears to have been determined very largely by the magnetic properties of the annealed alloys containing 25% and 30% chromium together with 6% and 9% nickel.

The boundary JK of the duplex $\gamma + \sigma$ field is founded on clear microscopic and magnetic evidence. For example, alloy 25/20 is completely austenitic, whereas that structure of alloy 25/15 shows the sigma phase definitely after annealing.

The properties of the higher chromium alloys are listed in Table III. Those of the alloys 35/30, 35/35, and 40/30 indicate that line JK ends at about 31% nickel and 35% chromium. Its prolongation to O, marking the boundary between the a and $a + \gamma$ fields, is founded on the results obtained by Jenkins and his co-workers (Fig. 5).

Considerable difficulties appear to have been met in determining the boundaries of the various fields in the chromium corner of the diagram, one being the absence of ferromagnetism in the alpha phase when its chromium content exceeds about 70%. Comment has already been made about the position of line BC. Schafmeister and

TABLE III.
STRUCTURE, HARDNESS AND MAGNETIC PROPERTIES OF ALLOYS CONTAINING OVER 30% CR.

No.	Composition.				2 hours 1,200° C., W.Q.			2 hours 1,200° C., W.Q., then (a) 200 hours 650° C., air-cooled. (b) 1,000 "			2 hours 1,200° C., W.Q., then 200 hours 800° C., air-cooled		
	C.	Si.	Cr.	Ni.	Structure.	Inductance Gauss.	Brinell No.	Structure.	Inductance Gauss.	Brinell No.	Structure.	Inductance Gauss.	Brinell No.
35/20	0·05	0·49	34·9	18·8	$a + \gamma$	Magnetic	245	$\gamma + \sigma$	Non-magnetic	(a) 310 (b) 363	$\gamma + \sigma$	Non-magnetic	330
35/25	0·04	0·38	35·1	24·7	$a + \gamma$	,,	232	$\gamma + \sigma$	,,	(a) 210 (b) 242	$\gamma + \sigma$	,,	221
35/30	0·02	0·24	35·4	31·1	$(a) + \gamma$	Non-magnetic	164	$\gamma + (\sigma)$	,,	(a) 168 (b) 185	$\gamma + (\sigma)$	,,	217
35/35	0·035	0·20	35·0	36·5	γ	,,	143	γ	,,	(a) 151 (b) 206	γ	,,	204
40/20	0·05	0·55	39·0	18·8	$a + \gamma$	Magnetic	302	$\gamma + \sigma$	Non-magnetic	(a) 420 (b) 500	$\gamma + \sigma$	Non-magnetic	425
40/25	0·05	0·55	38·7	24·5	$a + \gamma$	,,	238	$\gamma + \sigma$	,,	(a) 248 (b) 356	$\gamma + \sigma$	,,	295
40/30	0·05	0·67	38·9	30·6	$a + \gamma$	Weakly magnetic	221	$\gamma + \sigma + (a)$	,,	(a) 232 (b) 231	$\gamma + \sigma + (a)$	,,	268
40/50	0·09	0·31	41·2	48·1	γ	Non magnetic	—	$\gamma + a$	,,	—	$\gamma + a$	,,	—
45/8	0·06	0·44	45·4	8·0	a	5,900	304	σ	(a) 26	Broke	σ	29	Broke
45/18	0·05	0·38	45·9	18·4	$a + \gamma$	Magnetic	380	$\gamma + \sigma$	Non-magnetic	(a) 360	$\gamma + \sigma$	Non-magnetic	550
45/30	0·05	0·35	45·2	30·2	$a + \gamma$	Non magnetic	325	$a + \gamma$	,,	(a) 350	$a + \gamma$	,,	290
50/20	0·05	0·22	49·2	19·5	$a + (\gamma)$	Weakly magnetic	457	$a + \gamma + \sigma$	Non-magnetic	(a) 360	$a + \gamma + \sigma$	Non-magnetic	310
50/30	0·05	0·36	48·5	29·3	$a + \gamma$	Non-magnetic	385	$a + \gamma$	,,	(a) 358	$a + \gamma$	,,	3C0
50/40	0·06	0·32	51·6	38·8	$a + \gamma$	,,	—	$a + \gamma$	,,	—	$a + \gamma$	,,	—
55/10	0·05	0·36	53·6	9·9	a	Magnetic	360	$\sigma + (a)$	,,	(a) 415	$\sigma + (a + \gamma)$	,,	Broke
55/20	0·05	0·28	54·0	20·1	$a + (\gamma)$	Non-magnetic	510	$a + \gamma$	,,	(a) 380	$a + \gamma$	,,	329
55/30	0·04	0·33	53·1	29·7	$a + \gamma$	,,	480	$a + \gamma$	,,	(a) 390	$a + \gamma$	,,	300
60/10	0·05	0·24	61·8	9·7	a	,,	420	$a + \gamma + \sigma$	,,	(a) 400	$a + \sigma$	,,	440
60/20	0·06	0·25	58·6	20·2	$a + (\gamma)$	,,	480	$a + \gamma$	,,	(a) 400	$a + \gamma$	,,	333
60/20A	0·05	0·55	61·9	19·3	$a + (\gamma)$	,,	555	$a + \gamma$	,,	(a) 370	$a + \gamma$	,,	350
60/30	0·04	0·44	58·5	29·4	$a + \gamma$	,,	560	$a + \gamma$	,,	(a) 400	$a + \gamma$	,,	335
65/30	0·06	0·61	64·8	29·6	$a + \gamma$	,,	—	$a + \gamma$	,,	—	$a + \gamma$	,,	—
70/10	0·05	0·63	71·0	9·95	a	,,	—	a	,,	—	a	,,	—
70/20	0·07	1·10	72·2	19·6	$a + \gamma$	,,	—	$a + \gamma$	,,	—	$a + \gamma$	,,	—
70/30	0·06	0·40	69·5	29·2	$a + \gamma$	,,	—	$a + \gamma$	,,	—	$a + \gamma$	,,	—
80/10	0·05	0·70	78·7	9·6	a	,,	—	$a + (\gamma)$	,,	—	$a + (\gamma)$	,,	—
80/20	0·07	0·92	77·7	19·0	$a + (\gamma)$	,,	—	$a + \gamma$	,,	—	$a + \gamma$	,,	—

Ergang remark that alloy 45/8, after annealing for 200 hours at 650° or 800° C., consisted almost entirely of the homogeneous sigma phase, there being only a very slight amount of austenite visible. This alloy must therefore be close to the boundary between the σ and the $\gamma + \sigma$ fields. They also state that the boundaries of the three-phase field CGK could not be determined metallographically, as in that range of composition the alpha and sigma phases could not be distinguished with certainty; many varied etching media were tried but with no definite result. Several alloys were therefore tested by X-ray methods, with the results given in Table IV. It will be noticed that alloy 60/10 contained $\alpha + \gamma + \sigma$ after annealing at 650°, but only $\alpha + \sigma$ at 800°.

but the excess is not retained wholly in solution; a fine precipitate could be detected, and to this the high hardness value is attributed. During prolonged annealing this precipitate balls up, thus reducing the hardness.

The position of G appears to depend on the X-ray results on alloy 60/10, which, it may also be noted, contained some γ-phase at 650°, but not at 800° or 1,200°.

The line GN seems to have been positioned entirely by microscopic evidence obtained from alloys 70/10 and 80/10, the former consisting solely of the α-phase, whereas the latter—somewhat unexpectedly—contained also a small amount of the γ-phase after annealing. Schafmeister and Ergang mention, however, that the interpretation of structures at these high-chromium levels was made difficult

TABLE IV.
MICROSTRUCTURE AND X-RAY RESULTS.

No.	Composition.			W.Q., 1,200° C.		200 hours, 650° C.		200 hours, 800° C.	
	C.	Cr.	Ni.	Micro-structure.	X-ray.	Micro-structure.	X-ray.	Micro-structure.	X-ray.
30/20A	0·035	30·2	20·7	$\alpha + \gamma$	—	$\gamma + \sigma$	γ	$\gamma + \sigma$	—
35/20	0·05	34·9	18·8	$\alpha + \gamma$	—	$\gamma + \sigma$	$\gamma + \sigma$	$\gamma + \sigma$	—
40/20	0·05	39·0	18·8	$\alpha + \gamma$	—	$\gamma + \sigma$	$\gamma + \sigma$	$\gamma + \sigma$	—
45/8	0·06	45·5	8·0	α	—	σ	σ	σ	σ
50/20	0·05	49·2	19·5	$\alpha + (\gamma)$	α	$\alpha + \gamma + \sigma$	$\alpha + \gamma + \sigma$	$\alpha + \gamma + \sigma$	$\alpha + \gamma + \sigma$
60/10	0·05	61·8	9·7	α	α	$\alpha + \gamma + \sigma$	$\alpha + \gamma + \sigma$	$\alpha + \sigma$	$\alpha + \sigma$
60/20	0·06	58·6	20·2	$\alpha + (\gamma)$	α	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$
60/30	0·04	58·5	29·4	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$	$\alpha + \gamma$

Schafmeister and Ergang point out that X-ray analysis is not always sufficiently sensitive to detect phases present in small amounts only, and they instance alloy 30/20A, in which the sigma phase was not detected by this means though its presence could be seen definitely in the microstructure.
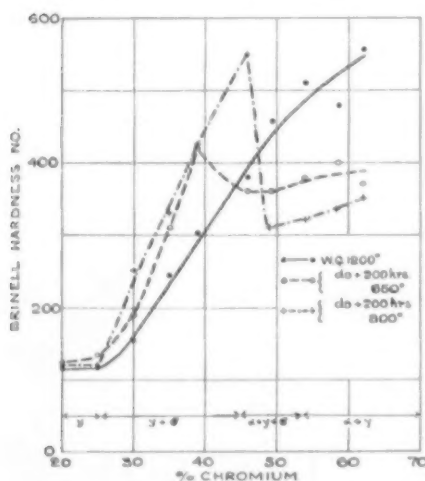
as a result of nitrogen absorption—a factor which they also encountered and investigated in greater detail in the iron-chromium-manganese alloys—and it may be that the presence of the γ-phase in the higher chromium alloy mentioned above was due to a higher nitrogen content in that alloy.

TABLE V.

Treatment.	Alloy 30/20A.		Alloy 40/20.	
	Magnetic Properties.	Hard-ness.	Magnetic Properties.	Hard-ness.
W.Q. 1,200° C.	Magnetic	162	Magnetic	302
Annealed 800° C.	Non-magnetic	190	Non-magnetic	425
,, + ½ hour, 850°	,,	190	,,	490
,, + ½ hour, 900°	,,	180	,,	460
,, + ½ hour, 950°	Magnetic	162	,,	460
,, + ½ hour, 1,000°	,,	,,	Magnetic	320
,, + ½ hour, 1,050°	,,	,,	,,	,,

Fig. 6.—Hardness values of 20% nickel alloys, after different treatments, plotted against chromium content.

Hardness measurements also enabled the authors to obtain some approximate corroborative evidence. In Fig. 6 the Brinell values of alloys containing 20% nickel are plotted against chromium content. In the quenched condition, hardness increases uniformly with chromium content. The greater rise in the hardness of the annealed samples above 25% chromium indicates the separation of the sigma phase and thus the overstepping of the line JK. The fall in hardness in these samples between 40% and 48% Cr is attributed to a decrease in the sigma phase as the triple field CKG is traversed. The further uniform but slight increase above 49% Cr indicates the progressive hardening of the alpha phase with rise in chromium content. The ranges of stability of the various fields, as drawn in Fig. 2, are indicated in Fig. 6. Incidentally, the marked fall in hardness produced by annealing the quenched higher chromium alloys at either 650° or 800°—particularly the latter—should be noted. A similar effect was found in the other alloys in the $\alpha + \gamma$ field OKGN, and Schafmeister and Ergang find an explanation in their microscopic observations. They point out that this duplex field widens markedly at lower temperatures. On quenching from 1,200° C. the α and γ solid solutions are each supersaturated,

The temperature at which the sigma phase is re-converted into the alpha phase was not determined accurately, but from the results of the following experiments was thought to lie between 900° and 1,000°. Samples of alloys 30/20A and 40/20, whose compositions lie in the $\gamma + \sigma$ field, were annealed for 200 hours at 800° C. and then heated for 30 mins. at 850°, 900°, 950°, 1,000°, and 1,050°. As is evident from the hardness and magnetic values in Table V, the conversion was complete at 950° in alloy 30/20A and at 1,000° in alloy 40/20. In order to determine whether the change would also occur at 950° in alloy 40/20 if more time were allowed, samples were reheated for periods up to 24 hours. After 2 hours the hardness value fell to 435, but no further change occurred in 24 hours. As the fall is so slight and the samples remained completely non-magnetic, it was concluded that no formation of the alpha phase occurred at 950° in this alloy. These temperatures agree fairly well with the following values given by Bain and Griffiths[1] :—

C. %.	Cr. %.	Ni. %.	Temperature $\sigma \longrightarrow \alpha$
0·32	41·3	9·3	964°
0·15	44·6	5·0	920°
0·19	45·5	10·0	957°
0·25	50·3	10·3	968°

Anti-Piping Compounds and their Influence on Major Segregation in Steel Ingots

By E. Gregory, Ph.D., M.Sc., F.I.C.

Experimental evidence is given to show that delayed freezing of the molten metal in the feeder-head produced by the application of anti-piping compounds and after-teeming, exerts a marked influence on the extent and position of major segregates in the ingot. The author expresses the view that major segregation in steel is a consequence of the initial separation of the homogeneous liquid metal into two liquid phases, followed by an enrichment of one or even both of the liquid conjugates as freezing or solidification progresses. This is abstracted from the advance copy of Paper No. 1/1940 of the Committee on the Heterogeneity of Steel Ingots, to be presented at the forthcoming May meeting of the Iron and Steel Institute.

THE formation of a contraction cavity, technically described as a " pipe," in an ingot of fully killed steel is inevitable, because of the marked contraction in volume which occurs during solidification. The shape and extent of the pipe depend upon such factors as the shape of the mould, the casting temperature, and the chemical composition of the steel. Higher carbon steels pipe to a greater extent than those of lower carbon contents, and the elements commonly employed as deoxidisers, notably silicon and aluminium, tend to exaggerate the volume change that occurs during freezing, and thus lead to a more extensive pipe. High teeming temperatures also tend to exaggerate the length of the pipe.

When ingots are cast with the narrow end upwards, the primary pipe may extend a considerable distance into the body of the ingot, and there is a grave risk of the formation of a " secondary " pipe lower down the ingot. In ingots cast with the wide end upwards the primary pipe is more squat—i.e., it does not extend so far into the ingot, and there is less risk of the formation of a secondary pipe.

Fully killed steels are generally cast with the wide end upwards. Feeder-heads, lined with some suitable refractory material, are placed on the tops of the moulds with the sole idea of decreasing the extent of the primary pipe. The lower thermal conductivity of the refractory lining of the feeder-head, compared with that of the cast-iron mould walls, serves to maintain the steel in a molten condition in the feeder-head for a considerably longer time than that in the mould. By this means, a reservoir of molten steel is maintained in the feeder-head, which serves to fill the contraction cavity that would otherwise be formed in the ingot. The object, therefore, is to confine the pipe within the feeder-head and thus to increase the proportion of usable material. Even under the best conditions, however, the surface of the metal in the head freezes shortly after casting, forming a " bridge " above the molten steel beneath it. The contraction cavity subsequently formed is usually divided in the manner indicated in Fig. 1, and in some cases, unfortunately, the pipe may extend into the body of the ingot, a difficulty which normally can only be overcome by using a deep feeder-head of proper design.

These difficulties are certainly real when using feeder-heads of normal height and shape, and have been mainly responsible for the development of the so-called " anti-piping " compounds. The main object of using these compounds has been to confine the primary pipe within the feeder-head and so to increase the proportion of useful material. Matuscha[1] has previously shown that these compounds exert a marked effect on the shape and disposition of the pipe. The term " anti-piping " is somewhat unfortunate, and to some extent is misleading, since, as already stated, pipe cannot be avoided in killed steels, as it is a natural consequence of the contraction that occurs during freezing. By means of these compounds, which are added in the form of powder to the surface of the molten metal in the feeder-head immediately after casting, a reservoir of liquid steel is maintained in the head for a

much more extended period. The result is the formation of an " open " pipe (i.e., there is no bridging) in the feeder-head, as represented in Fig. 2. The section indicated in Fig. 2 (a) represents the ideal case where the primary pipe consists essentially of a hollow shell. More often, however, the pipe takes the form of a hollow cone, as represented in Fig. 2 (b), in which case there is a greater possibility of the pipe extending into the body of the ingot.

Fig. 1.—Contraction Cavity in an Untreated Steel Ingot.
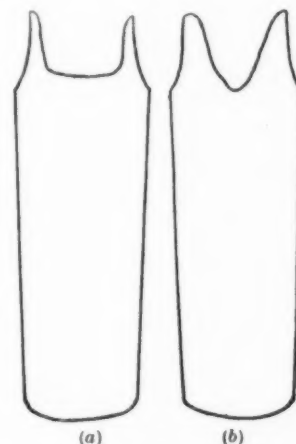
Fig. 2.—Contraction Cavities in Ingots treated with anti-piping compound. (a) Ideal ; (b) more usual form.

The chemical compositions of the different proprietary anti-piping compounds differ considerably, as is evident from Table I.

TABLE I.

COMPOSITIONS OF PROPRIETARY ANTI-PIPING COMPOUNDS.

Number :	1.	2.	3.	4.	5.
Al_2O_3 .... %	41·65	62·20	7·56	13·43	13·09
SiO_2 .... %	4·59	18·20	22·50	22·10	18·60
Fe_2O_3 .... %	2·52	2·60	3·50	6·10	1·71
CaO .... %	2·09	3·50	—	0·80	—
MnO .... %	0·17	—	0·44	—	0·09
MnO_2 .... %	—	—	—	—	—
Na_2O .... %	4·24	—	} 0·72	—	0·636
K_2O .... %	—	—		—	—
CO_2 .... %	6·02	—	—	—	—
Mg .... %	—	—	—	—	0·52
MgO .... %	0·52	2·89	0·21	0·65	0·23
CuO .... %	—	1·20	—	—	—
NaCl .... %	—	2·18	—	—	—
KCl .... %	—	0·36	—	—	—
Carbonaceous matter %	21·33	6·80	59·56	48·17	60·45
Volatile matter .... %	—	—	—	8·50	—
Loss on ignition.... %	—	—	—	56·82	63·50

Generally, therefore, these compounds consist essentially of mixtures of carbonaceous matter and irreducible oxides.

1 *Journal of the Iron and Steel Institute*, 1938, No. 1, 109 P.

When placed on the surface of the molten steel the carbon and any other elements present slowly oxidise, thereby generating heat. The non-metallic matter in the powder remains as a residue which serves to insulate the molten metal beneath. It is this combination of heat-generating and heat-insulating properties which serves to delay the freezing of the metal in the head to such a marked extent. As is well known, the old practice of covering the molten metal with hot coke had a similar object in view. The difficulty with coke was that considerable carbon absorption took place, often accompanied by an exaggerated pipe. Earlier experiments also indicated that carbon was absorbed from the anti-piping powders by the molten metal in contact with it. With some low-carbon steels, which normally do not pipe to any marked extent, carbon absorption occurred to such an extent as to convert them, in so far as the freezing of the metal in the head was concerned, into "fully-piping" steels. Later, however, compound No. 5 was obtained and the amount of carbon pick-up was then reduced to negligible proportions, even though it is rich in carbon. This compound was exclusively employed in the experiments recorded in this paper.

The primary object of this series of experiments was to determine the extent of the piped parts of blooms rolled from ingots cast (a) in the ordinary way, (b) treated with anti-piping compounds, and (c) treated with anti-piping compound and then "after-teemed." In the latter case, the feeder-head was refilled with molten steel after several other ingots had been cast.

When using the anti-piping compound alone, a period of about one hour elapsed between the casting of the ingot and the final freezing of the liquid metal surface in the head. During this period the liquid surface gradually sank to the extent of between 8 in. and 10 in. When both the powder and after-teeming were resorted to, the metal in the head remained molten for a period of between 1½ and 2 hours.

The object of after-teeming, of course, was to replenish the supply of liquid in the head and still further delay its freezing so as to obtain a shorter and more squat pipe of the type indicated in Fig. 2 (a). Generally, in regard to pipe, the anticipated results were obtained, the best results being obtained when the feeder-head was treated with the compound and then after-teemed. Unfortunately, there are other factors, which need not be discussed here, that preclude the general application of the combined method involving the use of anti-piping compounds and after-teeming. For certain steels, anti-piping compounds yield excellent results without the need of after-teeming : in some instances there are definitely some disadvantages associated with the use of these powders. Sets of sulphur prints are reproduced in the paper, taken from rolled blooms 9 in. by 9 in. in section taken from 67-cwt. ingots. The prints are in sets of three—viz. : (a) representing material rolled from an ingot cast with feeder-head only ; (b) metal in the feeder-head treated with anti-pipe compound ; and (c) the feeder-head treated with the compound and then after-teemed.

Treatment with Asbestos Sheet

Ingots were also cast and covered with asbestos sheet instead of the anti-piping compound in order to delay the freezing of the steel in the head. Even though only ⅛ in. in thickness, the asbestos was effective enough to permit of after-teeming, but the results obtained, although an improvement on the ordinary method of casting, were not quite so satisfactory as might have been expected. The extent of the pipe was generally less, but bridging almost invariably took place. Typical sulphur prints are reproduced in the paper, showing results where (a) the ingot was untreated ; (b) covered with asbestos ; and (c) covered with asbestos and after-teemed.

Influence of Delayed Freezing on Major Segregation

The main object of this paper is to draw attention to the influence of delayed freezing of the metal in the head on the position of the major segregates. The sulphur prints clearly shows that the zones richest in impurities are nearest

the top in the ingots treated with anti-piping compound and after-teemed, and occupy the lowest positions in ingots not treated in any way. Generally, too, the segregated zone does not extend so far—i.e., is much less elongated in the treated ingots that are after-teemed.

In order to determine the magnitude of the major segregation, drillings were taken from blooms rolled from certain casts. The analyses of the drillings indicate a really astounding concentration of the impurities sulphur, phosphorus, carbon and manganese in the middle positions of the major segregates.

In the "asbestos" series, similar results were obtained. The segregated zones, however, were considerably less rich in impurities, as might be expected from the fact that the freezing of the liquid metal in the head was not nearly so much delayed. It is to be noted also that in the asbestos-treated ingots the segregated zones are more elongated and not so clearly defined, even when after-teemed. A noteworthy feature is that there is apparently no connection between the base of the pipe and the position of the major segregate. The above facts are significant.

Interpretation of Results

Andrew and his collaborators[2] have expressed the view that major segregation in steel ingots is due to the formation of an immiscible liquid complex, rich in sulphur, phosphorus and other impurities. In the discussion of Andrew's paper, the present author considered this view to be too extreme, and suggested that a basic cause of major segregation may be the formation of a *partially* miscible liquid complex. On this basis, molten steel may be regarded as an emulsion of two conjugate liquid solutions, one much richer in impurities than the other, which tend to separate on prolonged standing in the ladle or moulds. The prevailing conditions prior to the commencement of freezing are thus comparable with those during the separation of a homogeneous solution of, say, phenol in water into two conjugate liquid solutions. When a clear and fairly concentrated solution of phenol in water is rapidly cooled a " cloudy " emulsion is obtained consisting of a saturated solution of phenol in water and a saturated solution of water in phenol. On standing, these solutions gradually separate into two distinct layers, the particles of the one possessing the greater density moving downwards and the other upwards. On standing, therefore, a clear liquid forms at the top and another at the bottom, separated by a cloudy layer which slowly diminishes in depth until eventually it disappears entirely, and two clear liquids, one upon the other, are obtained.

During the cooling of liquid steel, the conditions are not so simple. Almost immediately after the molten metal is poured into the mould, freezing occurs and the columnar crystals subsequently formed must necessarily impede the upward and downward movements of the two liquid conjugates. If the rate of rise and coalescence of the particles of the conjugate rich in impurities is much less than the rate of freezing, the impurities will be spread over a wide area. On the other hand, if freezing is delayed there is a far better chance of coalescence and the rising of the coalesced particles towards the upper part of the ingot.

Objection may be raised to this view on the grounds that there should be a marked line of demarcation between the microstructures of the segregated zone and the rest of the ingot, but this view may be discounted by the perfectly legitimate assumption that complete separation of the two conjugates into two liquid layers is never likely to occur in actual practice. Unfortunately, the problem cannot be completely and satisfactorily explained by reference to thermal equilibrium diagrams ; the system is quinternary at least, so that any true diagrammatic representation becomes impossible. It is of interest, however, to note that the existence of two liquid conjugates has been demonstrated in the Fe–FeS–MnS,[3] Fe–FeS–Fe₃P[4] and

2 Eighth Report on the Heterogeneity of Steel Ingots, Section II, *Iron and Steel Institute*, 1939, *Special Report* No. 25, p. 1.
3 Vogel and Bauer. *Archiv für das Eisenhüttenwesen*, 1933, vol. 6, May, pp. 495-500.

Fe–Fe₃C–FeS[5] ternary systems. The view has also been expressed that oxygen may contribute to the formation of liquid conjugates.[6]

In ternary systems exhibiting a region of partial or limited miscibility in the liquid state, the actual freezing may be accompanied by an alteration in the concentrations of the two liquid conjugates. Under true equilibrium conditions—i.e., with very slow rates of cooling, their concentrations gradually approach each other and eventually the residual liquid becomes homogeneous.

With quicker rates of cooling there is not enough time for equilibrium to be established, and it may then be assumed that the final liquid actually consists of two liquid phases which freeze independently. During subsequent cooling some diffusion in the solid state must occur, so that any sharp surface of demarcation that may have existed immediately after solidification of the two conjugates is masked in the final structure. When an alloy is cast into a mould with conducting walls, the rate of cooling is very rapid in the earlier stages and equilibrium conditions are not even approached.

Under ordinary conditions of cooling, ternary alloys cannot be expected to yield equilibrium structures, and with still more complex systems the departure from equilibrium will be still more marked.

4 Vogel und de Vries. *Archiv für das Eisenhüttenwesen*, 1931, vol. 4, June, pp. 613-620.
5 Sato. *Technology Reports of the Tôhoku Imperial University*, 1932, vol. 10, pp. 453-493.
6 Ziegler. *Revue de Métallurgie, Mémoires*, 1909, vol. 6, pp. 459-493.

As already stated, the existence of liquid conjugates in the Fe–FeS–MnS, Fe–FeS–Fe₃P and Fe–Fe₃C–FeS systems has been definitely established. It seems not unreasonable to assume, therefore, that in the more complex systems containing carbon, sulphur, phosphorus, manganese, oxygen, etc., in addition to iron, there is the possibility of the separation of the initial homogeneous molten steel into liquid conjugates which together constitute an emulsion. The rate at which de-emulsification can take place will depend on the casting conditions, although complete separation of the two liquids cannot be expected in practice. Nevertheless, by delayed freezing, there is a greater opportunity for the coalescence and separation of the particles of the conjugate liquid solutions.

Exponents of the differential freezing theory may raise objections to the above postulates. The author has no hesitation in stating that differential freezing is a fundamental cause of segregation in steel ingots, but considers that differential freezing is not the complete explanation, particularly in view of the remarkable degree of segregation associated with delayed freezing. Further, on the basis of this theory, the last material to freeze or solidify should be richest in impurities, so that these should be concentrated in the vicinity of the primary pipe. Careful examination of certain sulphur prints definitely indicates that there is no real connection between the pipe and the impure zone. In the present series of experiments it was only when freezing in the head was delayed that the position of the major segregate approached the base of the primary pipe cavity.

The Plastic Flow of Metals

By Hugh D. Mallon, B.Sc., A.R.T.C.

The problems to be solved in connection with the breakdown of metals under tensile stress are discussed. The mechanism of failure of a pure metal in the tensile test at room temperature is considered, and a hypothesis given as a result of a study of the type of deformation which takes place.

THE causes of the cup-and-cone type of fracture in the tensile test is only one of the interesting problems to be solved in connection with the breakdown of metals under tensile stress. In this connection, Professor B. P. Haigh (Trans. Inst. Eng. and Shipbuilders in Scotland, 1928–1929, vol. lxxii, p. 370) gives a rather interesting explanation of the phenomenon. According to him this type of fracture can be divided into two parts—firstly, the outermost regions of the test-piece where the metal fails by shear, i.e., by each crystal twisting and slipping along the appropriate crystallographic planes up to a limiting value, followed by fracture ; and secondly, at the centre of the test-piece where the metal is under what he calls " triple tensile stress " or " fluid tension " rather than pure unidirectional stressing, and where failure takes place without slip, when the true tensile strength of the metal is exceeded. An extension of these ideas prove interesting.

This hypothesis necessitates that, in the final stages of the test, the centre of the test-piece be subjected to what we will call hydrostatic pressure for want of a better term. The obvious conclusion is that the application of a unidirectional stress of any value tends to produce a hydrostatic pressure within the specimen. This hydrostatic pressure will vary according to the stress applied, and pure tensile fracture of the metal will occur when the unidirectional stress exceeds the pure tensile strength of the crystals (or the crystal boundaries), under the hydrostatic pressure produced by that stress.

The effect of hydrostatic pressure on a metal is well known. For example, bismuth at ordinary temperatures is a very brittle metal, so that a blow with a small hammer will shatter it. If subjected to hydrostatic pressure, however, bismuth can be very easily extruded, so that, in this operation, the brittleness appears to have been replaced

by plasticity, or, what amounts to the same thing, ductility.

A tensile stress applied to a material of high plasticity produces considerable elongation and, finally, fracture, if the stress is high enough. This type of fracture is characterised by the fractured ends of the test-piece being drawn out to a point, e.g., warm plasticine.

With metals the hydrostatic pressure produced will depend on the tensile stress applied, while the degree of plasticity produced by the hydrostatic pressure will depend on the nature of the metal being tested and also on the temperature of the test. Thus, for tests at room temperature, some metals would fracture with little or no elongation, due to the hydrostatic pressure produced being insufficient to give a reasonable degree of plasticity before the true tensile strength of the metal was exceeded. Other metals would become sufficiently plastic to allow considerable elongation before fracture took place.

Rise in temperature increases the plasticity of a metal, so that there are really two factors which determine plasticity, in addition to the inherent properties of the metal itself. A fixed value for the plasticity could thus be obtained by various combinations of temperature and hydrostatic pressure. Since plasticity is of vital importance in the resistance of metals to creep, this relationship between temperature and hydrostatic pressure in producing plasticity should prove interesting. It should be pointed out here that in order to compare the inherent properties (such as plasticity) of any pure metals it is necessary to invoke the principle of corresponding states. Thus, for example, if we wanted to compare the inherent plasticity of pure copper, aluminium, iron, magnesium, lead, silver, gold and nickel, instead of comparing them at room temperature, we should find for each a value for the

property at a temperature which is, say, half or one-third of the melting-point temperature in degrees absolute, and compare these values. Thus :

Metal.	Cu.	Al.	Fe.	Mg.	Pb.	Ag.	Au.	Ni.
Comparison temp. °C. (½ M. Pt.)..	179	37·6	328	35	−72·9	138	172	302

Suppose we consider the mechanism of failure of a pure metal in the tensile test at room temperature. Before any stress is applied the metal has a definite degree of plasticity, due to the temperature and the hydrostatic pressure. As soon as a tensile stress (no matter how small) is applied, the specimen should start elongating at a rate depending on the degree of plasticity. As the tensile stress increases so does the hydrostatic pressure, with consequent increase in plasticity and rate of elongation. But the hydrostatic pressure of the crystals at the surface of the metal cannot increase, as they can only be subjected to unidirectional stresses. The type of deformation which takes place at the surface of the metal has been studied with single crystals and test-pieces composed of only a few crystals, each of which had a surface exposed. With these, elongation was found to take place by a process of slip along certain crystallographic planes until fracture finally took place. Thus, with a normal test-piece, the surface crystals will deform by this rotation and slip, while the crystals in the core, subjected to hydro-static pressure, will flow plastically. The surface crystals can only elongate a definite amount, depending on the diameter of the crystal and the direction of the slip planes relative to the applied stress, after which the crystal fractures. Thus, as the elongation proceeds, the surface crystals will elongate and fracture, with the result that the next layer of crystals nearest the surface will then no longer be under hydrostatic pressure, and so will commence to slip in the same manner as the outer layer. Hence the layer of slipped crystals will penetrate progressively towards the centre of the test-piece as elongation continues, ceasing only when the tensile stress has exceeded the tensile strength of the metal and the test-piece fractures.

This slip of the outer layers of crystals in the test-piece is accompanied by hardening, as the single crystal experiments show. This hardening is sufficient to stop the elongation provided the stress is not increased, and is usually called work-hardening. A slight hardening effect would also be probable in the core of the test-piece. Just before fracture the core would be under quite considerable hydro-static pressure in order to increase the plasticity to give reasonable elongation. At fracture the stress is suddenly removed, and the plasticity of the crystals in the core would suddenly decrease—i.e., the crystals would " set." This process is analogous to quenching the metal suddenly from a temperature sufficient to give the degree of plasticity attained just before fracture to room temperature, with resulting strain in the lattice, which is known to give a slight increase in hardness.

This hypothesis can now be reviewed in the light of the results obtained from X-ray investigations into the nature of the mechanism of fracture. A normalised mild steel shows no change in the crystal structure within the elastic limit. Above this limit the lattices of a few crystals break down with the formation of small fragments or " crystallites," and what have been called " dislocated grains." After the yield point there are no perfect crystals remaining, while, at fracture, the metal is composed wholly of crystallites having no orientation.

A plastic crystal deformed by a tensile stress would be expected to give a distorted pattern unless the deformation of the lattice was regular, elastic, or was accompanied by recrystallisation so that irregular plastic deformation of the crystals may be the explanation of the " dislocated grains." The crystallites are probably formed at the slip planes of the surface crystals during the extension process by slipping, and the statement that the metal is said to consist only of crystallites at fracture would depend entirely on whatever part of the specimen was included in

the X-ray beam. Thus, the X-ray results may be con-sidered to provide slight confirmation of the hypothesis, and it can be said that they do not disprove it.

Magnesia from Brucite

IN the brucite deposits, the mineral brucite, which is a magnesium hydroxide containing 69·1% MgO, occurs in granular form, disseminated through crystalline limestone. The process developed consists in subjecting the brucitic limestone to a carefully controlled calcination at tempera-tures of about 1,000° C., maximum temperatures of 1,200° C., having, however, been used. To ensure uniform calcination, close sizing of the kiln feed is essential, accord-ing to a summary of the Canadian method of concentrating brucite, described in the January issue of *Canadian Chemistry and Process Industries.*

After calcination, the material is subjected to hydration, which converts the lime matrix to finely divided hydrate of lime, which is then separated from the unchanged brucite granules in an air separator. The brucite granules are subsequently washed and screened, the screens being equipped with water sprays to complete the washing process.

The purified brucite product from the screens is ready for dead-burning, if it is to be used in the manufacture of basic refractories, or it may be dried for other uses. A typical product obtained ran 94·40% of magnesia, with 4·38% water, 0·50% SiO_2, 0·59% Fe_2O_5, 0·38% Al_2O_3, and 0·40% CaO.

With brucitic limestone containing 25% or more of brucite, the cost of producing magnesia by the calcination process should not exceed $30 per ton, based on an output of 5,000 tons or more per annum. The possibilities of cheaper methods of recovering brucite—e.g., by froth flotation, electrostatic separation, gravity tabling with water and with air, and a combination of gravity tabling and agglomeration—are being investigated.

A New Factory for Light Metal Products

HIGH DUTY ALLOYS, LTD., has acquired a site approximat-ing 50 acres at Distington, Cumberland, with excellent rail and road facilities, for the erection of a factory equipped and staffed for the production of forgings, stampings, pressings, and extrusions in light alloys. Work has com-menced on the site, and the buildings are to be erected immediately. Arrangements have been made for the supply of electricity and gas, and it is anticipated that the works will be in production by September next.

Readers will be interested to learn that an agreement has been entered into with the Workington Technical School for the training of local labour, and for this purpose High Duty Alloys, Ltd., is installing £10,000 worth of plant in the school and is providing the necessary instructors and teachers. Local men will be trained in tool-making, die-sinking, and press and stamp operating, and it is anticipated that the works will employ up to 1,200 men when in full production.

Errata

OWING to an attack of influenza which incapacitated the editorial staff when going to press with the February issue, two or three errors in that issue have unfortunately occurred. On page 98, at the end of the last paragraph of the right-hand column, for instance, a sentence reads : " A view of a modern 1,000-ton furnace, from the cast-house side, is shown in Fig. 5." This should read : " A view of a modern blast-furnace stock-house of the Bethlehem Steel Co., showing scale car and bins of Baker suspension type, is given in Fig. 5." The caption to Fig. 5 should be deleted and the caption given to Fig. 6 transferred to Fig. 5. The caption to Fig. 6 should read : " A diagrammatic view of a modern American gas-cleaning plant."

On page 118, the caption to the bottom right-hand illustration should read : " Electrically operated pre-heating furnace for large-size billets."

The Fatigue Endurance of Killed and Rimmed Steels

In the solidification of rimming steel, the violent stirring action set up by escaping gases diminishes the amount of entrapment, and leads to a more pronounced segregation than occurs in killed steel, which may cause variation in fatigue endurance of these steels. An investigation on the subject is discussed.

THE failure of steels under repeated stresses below their ultimate tensile strength, and even below their elastic limit, presents a serious problem to the metallurgist and engineer. In many forms of steel construction, the subject of fatigue resistance is of vital importance, and as steel produced by different processes is used for such construction, it is of value to know how the process of manufacture affects the fatigue resistance of the steel. In the manufacture of certain parts, killed, semi-killed, and rimmed steels all find an outlet, and while these steels vary only slightly in general physical properties and chemical composition, they are structurally different at the surface and may vary quite materially in endurance. With a view to determining the fatigue resistance of such steels, an investigation has been carried out recently by J. F. McDowell,* with interesting results.

The tests were made on three steels—killed, semi-killed, and rimmed—all of approximately the same chemical analyses and physical properties, and consisted of the chemical, physical, micro and macro examination of specimens representing these three classes of steel, together with their fatigue values as determined from flat specimens on a machine designed to test plate under repeated bending stresses. The composition and physical properties of the steels tested are given in Table I.

(2) heat-treated in a neutral atmosphere at 870° C., and (3) heat-treated in a moist hydrogen atmosphere at 870° C. are given in Table III.

TABLE III.

Steel.	Yield-point, Tons per Sq. In.	Tensile Strength, Tons per Sq. In.	Elongation, %.	Brinell Hardness.
As received	23·1	29·3	39·0	131
Heat-treated, not decarburised	16·4	26·3	40·4	126
Heat-treated, decarburised	16·3	26·4	43·0	126

Test data showed that when this particular killed steel was heat-treated, but not decarburised, it had an endurance limit of about 12·6 tons per sq. in., which gave an endurance ratio of approximately 0·48, which is close to the 0·50 generally used. The decarburised sample had an endurance limit of 11.4 tons per sq. in and an endurance ratio of 0·43, a value which brings it in the range of the semi-killed steels.

Killed, semi-killed, and rimmed steels of approximately similar composition and nearly identical physical properties have, therefore, been shown to vary quite differently in

TABLE I.

Steel.	C.	Si.	Mn.	S.	P.	Yield-point Tons per Sq. In.	Tensile Strength, Tons per Sq. In.	Elongation, %.	Brinell Hardness.
Killed	0·20	0·16	0·50	0·034	0·012	17·21	28·41	41·4	131
Semi-killed	0·21	0·038	0·45	0·037	0·016	17·25	29·00	40·7	134
Rimmed	0·25	Nil	0·38	0·035	0·010	17·28	28·82	43·2	128

From the data obtained from the fatigue test specimens, the endurance limits of these steels were obtained, and from the endurance limits the fatigue endurance ratios of the three steels were determined and both values are given in Table II.

TABLE II.

Steel.	Endurance Limit, Tons per Sq. In.	Fatigue Endurance Ratio.
Killed	14·3	0·5
Semi-killed	12·05	0·42
Rimmed	10·7	0·37

From these values it is seen that the use of 50% of the tensile strength of a steel as being representative of the safe working stress holds true only in the case of killed steels.

In order to show that the low fatigue values of the semi-killed and rimmed steels are primarily due to a thin outer skin of low carbon composition, the following tests were made. Fatigue and tensile specimens of a killed steel, showing no decarburised edge, and having a composition of 0·21% carbon, 0·18% silicon, 0·54% manganese, 0·011% phosphorus, and 0·033% sulphur were made and then decarburised in moist hydrogen at 870° C. for 3 hours. A similar set of samples was given an exactly similar heat-treatment, but in a neutral atmosphere as opposed to the moist hydrogen atmosphere which produced decarburisation. Static tests carried out on the steels (1) as received,

their ability to withstand repeated stress reversals, and in calculating limiting stresses cognizance of this fact should be taken when either semi-killed or rimmed steel is involved. Previous investigations have shown decarburised surfaces to drastically reduce the fatigue resistance of medium and high-carbon steels, and this investigation has shown that skin decarburisation of 0·21% carbon steel has a marked influence on the fatigue resistance.

Segregation of other elements, particularly in rimmed steels, might possibly contribute to the lowering of the fatigue resistance of this type of steel. The data obtained in the present investigation, however, has shown that the segregation of elements other than carbon away from the skin of the metal can be considered to play a very minor role in the effect on the fatigue properties. That the carbon content of a steel is important, when considered in relation to fatigue, is shown by the well-known fact that fatigue resistance of steel increases with its carbon content up to approximately eutectic composition. The role of carbon is, therefore, doubly important at the skin of a steel when it is considered that the removal of this element through decarburisation lowered the endurance ratio of a killed steel sufficiently to place it in the category of the lower fatigue resistant semi-killed steels.

Spreading of the Material when Rolling Flat High-Carbon Steel Wire

MANY goods are produced by cold-rolling wire to flat strips with intermediate annealing and patenting—for example, needle-wire, fret-saw wire, spring wire, umbrella wire (paragon wire), etc. The carbon contents of these wires are between 0·6 and 1·3%. The final dimensions are between 0·0126 in. × 0·0063 in. and 0·472 in. × 0·157 in., and very small tolerances are allowed—e.g., for products of more than 0·2 in. width only + 0·006 in. Any thickness smaller than the original diameter can be produced, and it was the purpose of the investigation to find the rules according to which the width of the products could be predetermined under various working conditions.

After a survey of the literature a theory of the flow of the material is developed when wire is cold-rolled flat, and the experiments are described by Anton Pomp and Heinz Höhle which have been carried out to prove this theory.

Four steels are used of different analyses, two electric steels of 1·11 and 0·83% carbon, and two open-hearth furnace steels of 0·50 and 0·70% carbon, but the main experiments have been made on the electric steels. They have been subjected to various processes so that different structures and different mechanical properties have been obtained.

The results of the investigations can be summarised as follows :—

(1) The increase of the width increases with the decrease of the thickness and with the increase of the diameter of the rolls.

(2) Various carbon contents and structures have no practical effect on the increase of the width.

(3) The lubrication of the wire and the roll faces causes a small decrease of the spreading of the material.

(4) The number of passes and the sequence of the passes have only small influence.

(5) The rule of thumb often used in practice for determination of the original diameter, $d = 0·5 (b + h)$, when b = final width and h = final thickness, has been proved and found practically correct in some cases, but has given great deviations in others.

This last fact was the reason to carry out special investigations in order to find more reliable figures for practical use. Two diagrams have been elaborated for rolls of 4 in. and 6 in. diameter respectively, by means of which the initial diameter can be determined for any final dimensions when the material is rolled without lubrication. Some examples are given how to use these diagrams.

Determination of the Initial Diameter of Wire before Rolling it Flat into Strips of Given Dimensions

Theoretical considerations by Werner Lueg and Anton Pomp show that the results of rolling processes must be geometrically similar if the rolling takes place in geometrically similar conditions. That means in the case of rolling wire to flat strips that, for various diameters of wire and rolls the ratio of the spreading to the wire diameter must be the same if for different rolling processes the reduction per pass as well as the ratio of wire diameter to roll diameter is the same. If this assumption is correct, it must be possible to find relations between wire diameter, roll diameter, and strip section, which are generally correct and valuable for the rolling practice.

It was the purpose of this investigation—

(1) To prove the correctness of this consideration when relying on the results of the foregoing investigation of Pomp and Höhle ; and

(2) To develop a universal diagram for the determination of the initial wire diameter if roll diameter, width and thickness of the final strip are known.

Both these purposes could be obtained, and the results of the former investigation made it possible to draw this diagram for the ranges of : Thickness of the strip, 0·004 in. to 0·2 in. ; width of the strip, 0·008 in. to 0·4 in. ; diameter of the wire, 0·004 in. to 0·4 in. ; diameter of the rolls, 0·4 in. to 24 in.

Each of these four sizes can be determined by means of a diagram if the other three sizes are known ; further, other problems which may arise when wire is cold-rolled into strip, can be solved—as, for example, manufacturing strip which has to be cold-deformed in a manner determined in advance, finishing of a rolling process which has been interrupted for some reason, establishing a rolling programme of a certain mill, etc.

Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zn Dusseldorf, vol. XX. No. 14.

Report of Bureau of Analysed Samples

DURING the past year the Bureau of Analysed Samples Ltd. has issued the following new standards with preliminary editions of the certificates of analyses :—88–10–2 Gunmetal named Bronze " C " (No. 207). High Silicon and High Phosphorus Cast Iron (No. 206).

The following new standards are in course of being analysed :—78–80% Ferro-manganese Steel (No. 208). 18–8 Stainless Steel (No. 209).

It is interesting to note that Bronze " C " is the first standard to be prepared to correspond with the B.S.I. specification for gunmetals, and indicates the policy which the Bureau decided to follow as far as possible, after discussing with the Director of the British Standards Institution in what way his Institution and the Bureau could collaborate. It is also noteworthy that some months ago, when a sub-committee of the British Iron and Steel Federation was investigating the question of rapid reliable methods of analysis, it applied to the Bureau for a supply of several British Chemical Standard Cast Irons to assist it in the investigation of the combustion method for sulphur. Furthermore, its official figure for sulphur by the combustion method was published in the certificate of analyses of Cast Iron No. 206.

War conditions have resulted in a somewhat greater demand for our standard samples, though our regular business with Poland and Czecho-Slovakia has, of course, ceased.

It will be re-assuring to the many users of British Chemical Standards to know that as a precautionary measure, shortly after the outbreak of war, a certain number of all the certificates of analyses, also some of each of the finished standard analysed samples, including some of the steel bars, were stored in a different locality to ensure continuity of records and supplies in the event of the main bulk of standards and certificates at Middlesbrough being damaged or destroyed.

In view of the increased costs due to war risks insurance, printing, packing materials, etc., it is proposed to advance prices of standards and students' samples by 5% which is regarded as a very moderate figure and will no doubt be readily accepted by our clients under the present circumstances.

Spectro-chemical Analysis.—Interest in spectro-chemical analysis for steel is growing and the Bureau is giving some thought to the advisability of preparing a series of suitable standard pieces.

Galvanised Wire Netting and Cloth

A SPECIFICATION has recently been issued for galvanised wire netting and cloth which embraces the material designed for covering windows and other glass to reduce flying splinters from the blast effect. It covers the size of mesh, the diameter of the wire, the weight and length of the roll.

Copies of this specification may be obtained from the British Standards Institution, 28, Victoria Street, London, S.W. 1, price 3d. post free.

Progress of the British Machine Tool Industry

The manufacture of machine tools is probably the most important key industry in any industrialised country, because they enter directly or indirectly into the making of everything else. For many years the British machine-tool industry was under a cloud and its products lagged behind those of certain other countries. This position has changed considerably in more recent years, and to-day marked progress in design and the high quality of British machines make them at least equal to the machines of any other country. In this article developments are briefly reviewed, and some factors which have contributed to them are briefly discussed, but mention should also be made of the courage and resourcefulness of the industry in overcoming the difficulties with which they were confronted for many years.

RECENT years has seen many outstanding developments in machine-tool design, and at a time when the engineering firms have re-equipped or are re-equipping their shops to meet the abnormal demands made upon them by the rearmament programme and by the war conditions now existing, it seems opportune to review briefly these developments in so far as they apply to the British machine-tool industry. In doing so, however, it is necessary to mention the difficulties with which British machine-tool makers were surrounded at a time when progress was vital to the industry.

It will be remembered that important advances in the manufacture of tungsten-carbide cutting tools were made which not only stimulated progress in machine-tool design, but also had a considerable influence in the development of machine-shop production methods designed to make the best use of the new cutting materials. Tungsten-carbide cutting materials became available in the years following the war of 1914-1918, when the British machine-tool industry was in a perilous state due to causes which are discussed elsewhere in this issue. It was at this time that the practical disappearance of the home market and lack of financial support seriously handicapped British designers in meeting the problem. The Machine Tool Exhibition of 1928 demonstrated the cutting qualities of various new cutting materials, but higher cutting speeds and heavier cuts were necessary to take full advantage of them, which imposed duties on many machines they were never designed to bear.

The vastly greater scope of United States and German machine-tool makers in the respective domestic markets had a very great influence at this critical time, and it is not surprising that the British machine-tool industry was left behind, especially by American productions. For a number of years firms were justified in showing a preference for American machine tools, but, excepting for certain special purpose machines, there is no justification for that preference to-day, although for some extraordinary reason some machine-shop managers continue to think that a first-class foreign product must be better than a first-class British product, and they are generally prepared to pay more for their preference, even when the differences between two similar machines are insufficient to warrant it. It is recognised, of course, that American machine-tool makers have such an enormous home market that it pays them to develop highly specialised labour-saving machine tools, which it also pays British firms to use, and these comments do not apply in such special cases.

Readers who were able to make comparisons between British machine tools shown at the 1928 Exhibition and that held six years later, would appreciate the tremendous progress made in that relatively short time. The British exhibits on the latter occasion proved a revelation to British engineers and to engineers from all over the world. The progress and advancement was such that British machine-tool design compared favourably with that of America, Germany or Switzerland among the exhibits. During the past six years the industry has been able to consolidate its
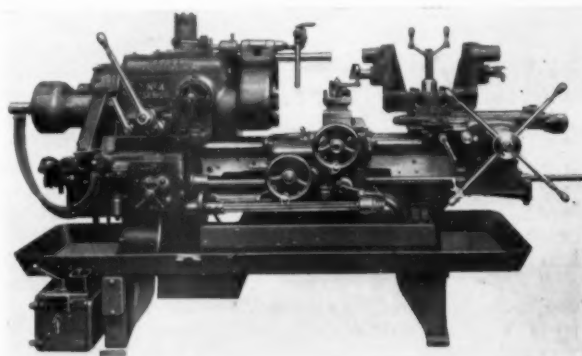

Fig. 1.—The Herbert No. 4 Senior capstan lathe.

position and to concentrate further on the development of its products. The main developments which have been made in the machine-tool products of Alfred Herbert, Ltd., may be briefly summarised as a typical example capable of being applied to the British machine-tool industry. These are as follows :—

1. Greatly increased speeds and power to enable tungsten carbide and other high-speed cutting tools to be used to full advantage.
2. An increase in the weight and stability of beds and frames to prevent chatter or vibration at the increased speeds.
3. The use of anti-friction bearings on spindles and driving shafts.
4. Hardened gears of chrome-nickel running under automatic lubrication.
5. The protection of beds and slides by covers which are in contact and therefore prevent the ingress of even the finest chips.
6. The universal adoption of direct connected motor-drive, frequently by the use of motors forming an integral part of the machine.
7. The complete guarding of all rotating parts which could cause injury to the operator, and the provision of means to facilitate ease of handling.
8. The use of air chucking equipment, which enables high production to be maintained without fatigue.

These developments are incorporated in the Herbert No. 4 Senior capstan lathe shown in Fig. 1. This machine is fitted with the Herbert preoptive headstock, which is claimed to be the greatest development since the introduction of the single pulley head ; it enables any speed between 42 and 1,000 r.p.m. to be selected in advance while cutting is in progress. By simply moving a lever, the speed is changed instantly under cut to any selected speed desired. Considerable savings in time are effected by this new method of speed-changing when machining work with turning, boring, facing, screwing and other operations on parts having a number of different diameters. The wide
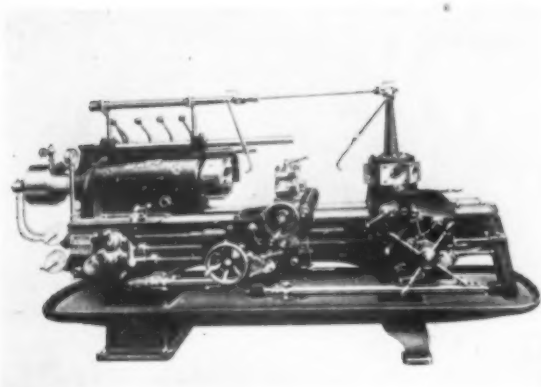
Fig. 2.—Medium-size (No. 7) combination turret lathe by H. W. Ward and Co., Ltd.

speed range makes this headstock very suitable for high-speed cutting tools.

The main spindle in the headstock is mounted on large parallel roller-bearings, while the thrust in both directions is carried by two opposed double-purpose ball bearings, which also take part of the journal load. All the spindle bearings are of the precision type and have their inner and outer faces clamped. They are carried in two massive housings integral with the headstock.

A typical example of the latest type of medium size combination turret lathes is shown in Fig. 2. This machine, by H. W. Ward and Co., Ltd., incorporates several developments, including patent bed covers, ball and roller-bearing headstock, automatic lubrication, ground gears, etc. The machine illustrated is fitted with a 3-jaw compressed air operated chuck. This latter is designed to meet the demand for a rigid high-speed machine which will allow the use of tungsten carbide cutting tools to their maximum efficiency.

The single-pulley geared headstock is very sturdy and powerful ; the spindle is mounted on roller journal and combined journal and ball-thrust bearings of large diameter, and all gear-shafts are mounted on ball and roller bearings. Eight speeds are obtainable in either direction, while the speed of the driving shaft can be altered to give different speed ranges. The driving clutch consists of two metal cones, internal and external respectively, held in engagement when driving by a compression spring. Gear changes cannot be made until the driving clutch is disengaged, and as every lever withdraws the clutch and applies a brake before the gears can be moved, speed changes are effected under " no-load " conditions.

The saddle has automatic sliding, surfacing, and screw-cutting motions. The sliding and surfacing feeds are operated by the same lever, so that it is impossible to engage both simultaneously, opposite motions of the lever being required. An interlocking arrangement prevents the use of the screw-cutting motion when either of the other feeds is in engagement. Automatic lubrication by pump is provided to all moving parts of the saddle and apron, including the saddle-bearing on the lathe bed. The cross-slide is of high-tensile steel, with a square turret giving four tool positions, and an adjustable two-way rear tool-post.

The train of wheels in the gearbox provides motion to two independent feed-shafts and the leader screw. Variations in speed provide three changes to the lead screw, ten changes to the sliding and surfacing feed-shaft, and five changes to the turret feed-shaft. A convenient change on the turret saddle increases the gearbox changes, so that ten feeds to all motions can be obtained.

The bed covers do not move, and as a result of this they never overhang the bed and are not subject to abuse or accidental breakage. No part of the bed is ever exposed to cuttings, and this feature, together with the automatic lubrication, results in long life to the bearing portion of the

bed and retention of the original accurate alignments over long periods. A steel rule is fitted to the front cover, and the turret saddle is provided with an adjustable pointer, these features being of great help to the operator when setting up or making single pieces.

Although remarkable progress has been made in the design of what may be regarded as the smaller forms of machine tools for mass production work, great progress has also been made in large machines, and while mention could be made of many planers which come into this category, the planing machine by Craven Bros., Ltd., shown in Fig. 4, may be taken as a typical example. This machine, which was recently shipped abroad, is probably the largest of its type to be built in this country. It will plane work up to 17 ft. wide, 13 ft. 3 in. high, and up to 60 ft. in length ; it is equipped with three toolboxes, three on the cross-slide and one on each upright. An interesting comparison with this modern high-speed machine is shown in Fig. 3, which shows a planing machine built by the same firm in 1903, and which was designed to a planing capacity of 6 ft. wide, 6 ft. high, and 18 ft. long.

The contrast between the two machines gives a fair indication of the measure of advancement in planing machine design made over a period of years. Many intermediate designs, of course, have been made, but these two illustrations unmistakably show the period to which the respective machines belong. It will be noted that the 1903 machine had the overhead motor drive, as many other early motor-driven planers had.

In the modern machine, the main drive is by " Ward-Leonard " planer equipment, separate auxiliary motors being provided for driving the feed and quick-traverse mechanism, and for raising and lowering the cross-slide. The twin motors for the main drive are each 75 h.p.

The cross-slide has two screws for the horizontal feed or traverse, and two shafts for operating the feed of the vertical toolbox slides. One screw and shaft controls two of the toolboxes which operate in unison so far as the feed and traverse movements are concerned. The other screw and shaft control the third toolbox. Provision is made for the disengagement of the feed drive to the vertical slides. The cross-slide toolboxes are arranged to swivel and have self-acting feeds both horizontally and vertically. They are of heavy construction, the front slide is a steel casting, and the saddle slides on square-section ways. Current for energising the magnet coils on the cross-slide toolboxes is fed through collector bars fitted along the cross-slide. A switch on each toolbox renders the magnet coils independently inoperative when desired. The feeds provided for the cross-slide toolboxes are horizontally $\frac{1}{32}$ in. to $\frac{3}{4}$ in. and vertically $\frac{1}{64}$ in. to $\frac{3}{8}$ in., and the vertical feed to the side toolboxes is $\frac{1}{32}$ in. to $\frac{3}{8}$ in.

The machine is fitted with independent power feed and quick traverse motion which is driven by $12\frac{1}{2}$ h.p. motor. All motions can be reversed and all feed motions can be thrown out of gear without stopping the machine. The box-section cross-slide is raised and lowered on the uprights
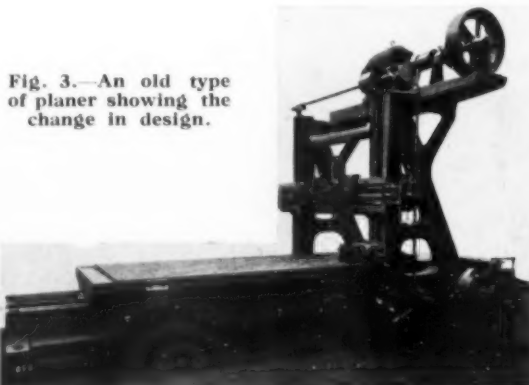
Fig. 3.—An old type of planer showing the change in design.

at a speed of 2 ft. per min. through two vertical screws provided with ball-thrust bearings, power being obtained from a 15 h.p. motor mounted on the top of the machine.

The table is 15 ft. wide and has four flat sliding surfaces. It is driven by two bull wheels gearing with two steel racks bolted and keyed to the underside of the table, the gearing being of steel. The shafts carrying the gears are supported on long trunnion bearings carried in the bed.

The driving gear gives the following table speeds :—High range—Cutting : 24 ft. to 75 ft. per min ; return, 24 ft. to 120 ft. per min. Low range—Cutting : 15 ft. to 37 ft. per min. ; return, 15 ft. to 75 ft. per min. The stroke is set and the reversal of the table is controlled by knockers adjustable in a groove machined in the side of the table.

The bed is 123 ft. long, or rather more than double the machine has to plane, so that the table is fully supported in all positions. It has a continuous plated top and is strengthened in the centre portion where the driving gears are located. The four sliding ways are lubricated by rollers carried in pockets at intervals along the ways, an auxiliary pump replenishing the oil supply in the pockets. The uprights are massive box castings, keyed and bolted to the bed and tied together at the top by a heavy cross beam. When clamped in position, the cross-slide forms an additional tie between the uprights.

A pendant push-button switch on each side of the machine gives "start," "stop," "inch" and "inch return" for the main motor ; "feed-on" and "feed-off" for the feed motor ; and "forward" and "reverse" for the quick traverse motor. "Raise" and "lower" push-buttons control the cross-rail elevating motor.

The weight of this machine exclusive of its electrical equipment is 375 tons, and therefore should not be regarded as typical in size but of development in this type of machine.

Many firms make a speciality of drilling and boring machines and vast improvements in these machines have been made in recent years. Of these, mention may be made of developments made by William Asquith, Ltd., who have concentrated on a symmetrical compact design for their high-speed vertical drilling and tapping machines. All working controls on these machines, with the exception of those for the table motions, are concentrated on the front of the drilling head. The number of handwheels and levers is reduced to a minimum and arranged for ease and handiness in operation. All speeds are obtained by movement of a single lever and direct-reading disc. Improved
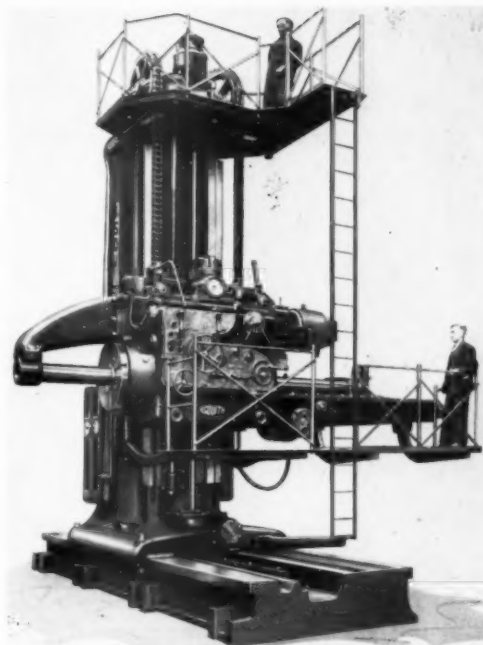

Fig. 5.—A horizontal boring machine by William Asquith, Ltd., carrying an 8-in. spindle.

automatic trip to spindle-feed, with special scale for point correction.

In the case of radial drills also the outstanding trend is towards simplification of operation, all working controls being concentrated within the smallest possible area on the spindle slide itself. Furthermore, the number of handwheels and levers is kept down to a minimum, and wherever possible these are endowed with multiple functions as, for example, the patented master control switch and combined locking lever. Drive by means of motor mounted directly on the spindle slide is a feature of these machines, thus bringing the driving member as close to the spindle as possible, cutting out much shafting and gearing and reducing frictional losses.

The design of these machines makes them particularly suitable for the practice of multiple setting, whereby work

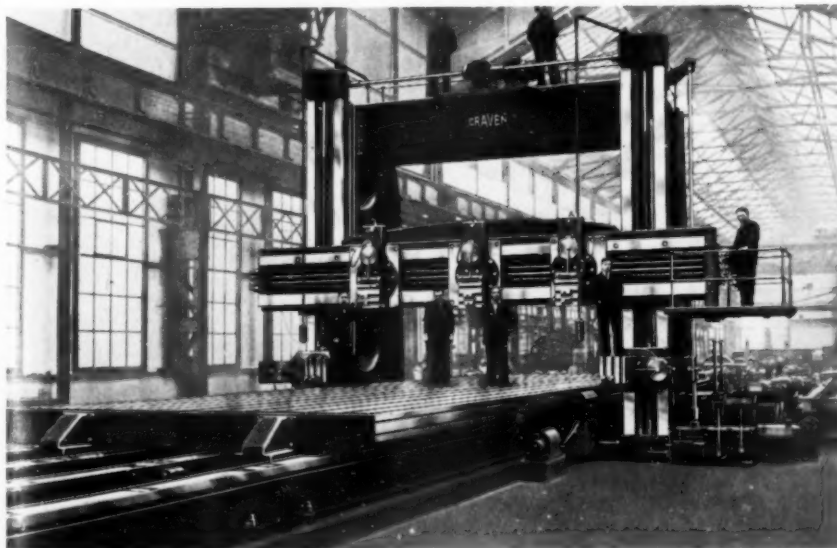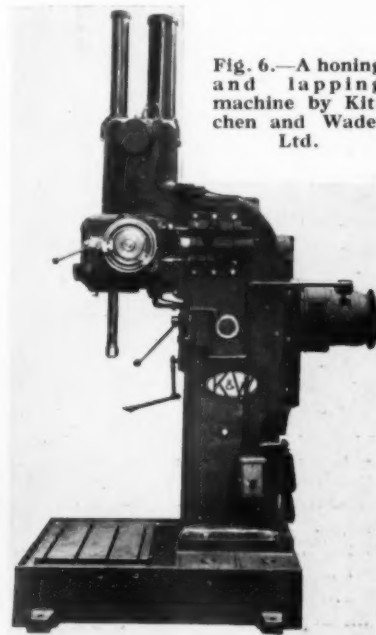Fig. 4.—Large high-speed planing machine by Craven Bros., Ltd.

Fig. 6.—A honing and lapping machine by Kitchen and Wade, Ltd.

is set up and removed at one or more stations whilst drilling is proceeding at another, thus practically eliminating " idle " time. This practice is facilitated by the provision of collector gear at the pillar top, enabling the arm to be swung continuously through complete circle.

Similar improvements have been applied to horizontal drilling and boring machines. A machine of the latter type is shown in Fig. 5. It is an 8-in. spindle machine fitted with an overhanging arm on the front of the slide to give support to the cutter when the machine is used for heavy milling operations. Despite the massive design of this machine, facility of control is a feature. The elevating and lowering of the slide on the column and the traversing of the column along the bed are operated by two independent control levers, which indicate definitely to the operator the direction of traverse.

A range of drilling and boring feeds is provided for use with any spindle speed, whilst there are also special ranges for use with single, double or treble gear. This system enables advantage to be taken of the extra coarse feeds that can be obtained for operating on large boring work.

Another British maker of drilling and boring machines of repute is Kitchen and Wade, Ltd., but in recent years this firm has given some attention to honing and lapping machines, and Fig. 6 shows an improved hydraulically operated machine of this type. It is designed primarily to meet the needs of the aircraft industry, and has already proved itself capable of meeting requirements, even when lapping internally and externally at the same time. Very fine degrees of accuracy are obtained, and either a " mirror " or " matt " finish may be obtained as required. Four sizes of these machines are available, the smallest having a capacity of ⅛ in. to 2 in. diameter with 6 in. as the maximum length of hole, while the largest has a capacity of 2 in. to 9 in., with 20 in. as the maximum length of hole.

The honing spindle, housed in the head, is balanced on ball bearings, and the trip gear, also carried in the head, operates by adjustable dogs on a large disc, so that any predetermined stroke can be obtained. These dogs provide automatic reversal to stroke, actuating the reverse lever. The latter is of special design, and can also be used to withdraw the spindle to its top position, a very important feature for unloading and loading. It is noteworthy that the spindle is made from hardened Nitralloy steel to ensure non-wearing qualities. It is 6-splined to British Standard Specifications, and is driven by a phosphor-bronze sleeve from the driving gears. Heavy ball thrusts take the reciprocating stresses, and a clear-reading tachometer at the front of the machine records the speed in use.

Precision Grinding Machines

No reference to the present trends in machine-tool design, however brief, would be complete without some mention of the recent outstanding developments in precision grinding machines. The manufacture of this type of machine differs largely from that of the majority of machine tools, since precision grinding is generally the final finishing operation and the machines must, therefore, be built with a precision considerably greater than that for machine tools generally, in order to be capable of producing work consistently to the very fine tolerances required to-day by machine-tool users.

Precision grinding machines are now carrying out many operations, which until a comparatively short time ago could be performed only by other types of machine tools or by hand. In the latter case, accuracy of the results and the quality of finish produced depended entirely on the skill and experience of the worker. The Slideway grinding machine shown in Fig. 7 is a typical instance. This machine grinds all types of machine-tool ways and slides in a fraction of the time previously taken by scraping the surfaces by hand. Apart from the very great savings of time, ground surfaces are more consistently accurate, and there is reason to believe they have better wear-resisting qualities than have hand-scraped surfaces. Many leading firms have already adopted slideway grinding as a standard practice.

Developments in other types of grinding machines have been no less remarkable, and possibly the most interesting examples are shown in the applications of automatic sizing and automatic operation to internal and external grinding machines. The Churchill grinder of this type, shown in Fig. 8, was introduced a few years ago, and is now claimed to be the world's fastest internal grinder. This design operates on the plunge-cut principle, and is undoubtedly one of the most notable grinding machines in the production shops to-day.

An interesting feature of the latest machine of this type enables the operator to repeat the wheel-truing operation in each direction without interfering with the automatically timed operating cycle. He can true the wheel both forward and reverse as frequently as required before allowing the grinding wheel to enter the hole for the commencement of the automatic operating cycle. This feature is of particular value where extremely fine finish is required, as on ball- and roller-bearing work. For the usual good commercial finish the normal method of working is entirely satisfactory.

As is generally known, the above machine has its complement in the traversing type machine (Fig. 9), which deals with holes which are too long for grinding by the plunge-cut method. A variable period of dwell at sizing position can be applied on this machine whenever necessary, in order to obtain the extra fine finish sometimes desirable on certain classes of work. The light indicator operates automatically throughout an auxiliary dwell period, which is pre-set according to the class of work and the particular finish required. The light is automatically cut out at the end of the auxiliary dwell period, and the automatic operating cycle continues in the normal manner.

Considerable progress has also been made in the development of external grinding machines. When fitted with automatic diminishing feed, the Churchill plain grinder, as illustrated in Fig. 10, becomes fully automatic in operation as it is only necessary for the operator to insert the work, start the machine, and remove the work when the head runs back. The operator moves only one lever for the machine to begin and complete its cycle. The automatic diminishing feed feature, which is exclusive to these machines, includes full hydraulic control of wheel-head, giving quick withdrawal and return to pre-set position just short of the work. Hydraulic feed continues rapidly at first, and then progressively more slowly right down to dead size. When size is reached the head returns quickly to the withdrawn position. An adjustable period of dwell at sizing position can be applied when necessary. During the sizing dwell a signal light operates automatically.
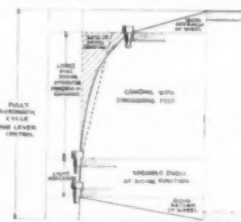

Fig. 11.—A diagram showing the diminishing feed feature.

The principle of the diminishing feed feature is shown by the accompanying diagram (Fig. 11), which also explains one of the reasons for the remarkable output times obtained on these automatic plain grinding machines. The dotted line shows the metal removal, with the usual constant plunge feed rate of the ordinary grinding machine. To obtain the same result without diminishing feed, a much longer period of dwell at the sizing point would be necessary, thereby reducing output.

The Application of Ball- and Roller-Bearings to Machine Tools

Among the many factors that have contributed to development in machine-tool design is the application of ball- and roller-bearings. Although this type of bearing has offered a wide field of application in machine-tool design for many years, where extreme accuracy was not essential, it is only during relatively recent years that precision bearings manufactured to the highest and most uniform degree of concentricity have been available.
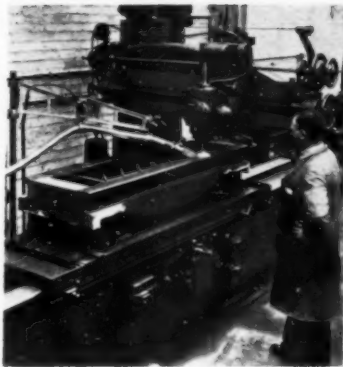
Fig. 7.—A Churchill slideway grinding machine for grinding machine-tool ways and slides.
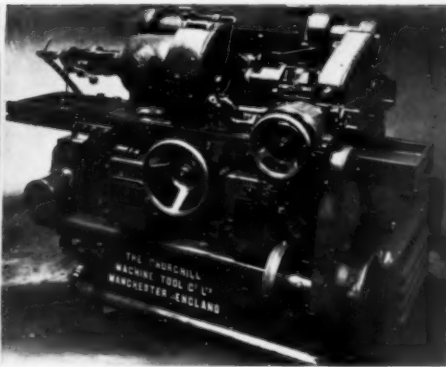
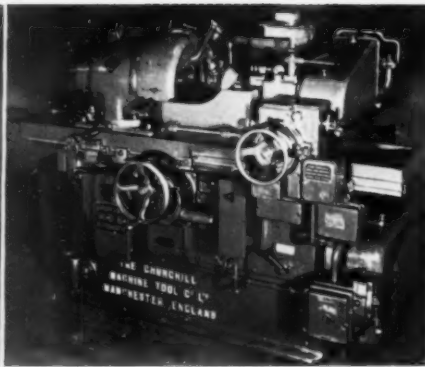Fig. 8.—The Churchill Model " HBA " automatic sizing internal grinder.

Fig. 9.—The Churchill Model " HBB " traverse type grinder for holes which are too long for grinding by the plunge-cut method.

For a number of years prominent ball-bearing manufacturers like Messrs. Ransome and Marles Bearing Co., Ltd., British Timken, Ltd., and others, experimented with the application of ball- and roller-bearings for machine tools. As a result of these experiments, it was found that whilst ball- and roller-bearings permit of the minimum running clearance between the revolving elements and the tracks, under load there is deflection, and this deflection for light loads is relatively greater than for heavy loads. It will be appreciated that for machine tools, unless the spindles are held rigid—i.e., without axial or radial movement, irregularities such as chattered surfaces will be present on the work produced.

Experiments proved that by giving an initial deformation to the tracking surfaces before applying the " work load " the deflection in the bearing was nullified. A bearing subjected to this procedure is " pre-loaded," the term applying to the stresses in the bearing itself which overcome the initial deflection. The use of pre-loaded bearings has therefore enabled the adoption of this class of anti-friction bearing to all forms of machine tools.

The amount of " pre-load " which is best determined by experience, is dependent upon the value of the subsequent " work load " which the bearing must sustain. The methods adopted to pre-load bearings are : By so disposing the tracks in relation to the faces of the bearing that when the bearing is mounted and secured laterally in position there is an initial load on the bearing ; and by taking advantage of the internal construction of the bearing, such as occurs in double-row angular contact bearings (having one-piece inner and outer race rings), the manufacturer, in assembling the bearing, can arrange for an accurately pre-determined deformation of the balls. Angular contact bearings are particularly adaptable for pre-loading. These can be supplied in double-row construction, or, alternatively, single-row bearings can be supplied in pairs, the latter being a popular procedure. Such bearings are controlled by the manufacturer to a very close degree of accuracy, and when fitting pre-loaded bearings it is necessary for the shaft, housing, etc., to be ground to the closest possible degree of accuracy. Squareness of abutment shoulders on shafts and housing is of particular importance, and attention must be paid to the roundness of shaft-seats, housing bores, alignment, etc. Owing to the extreme rigidity of the bearing arrangement, any slight out-of-roundness or other errors might stress the bearings to a dangerous degree. A typical application of pre-loaded bearings, designed by Ransome and Marles Bearing Co., Ltd., for application to a lathe headstock, is shown in Fig. 12.

The roller bearings have no diametrical clearance when supplied by this manufacturer, and the interference imposed through fitting the bearings to the spindles slightly pre-loads the roller bearings. The ball bearings, which are of the angular contact type, are manufactured so that when mounted back to back as indicated and clamped laterally

they are pre-loaded in the manner described above. The three bearings mounted at the nose end are graded with regard to bores and outside diameters, so that the fitting diameters of each bearing are the same to within the finest limits. This is an arrangement of bearings which has proved not only satisfactory on lathe headstocks, but also on milling spindles.

Fig. 13 shows the arrangement of a ball-bearing grinding spindle, and in this a spring-loaded arrangement is provided. This spring loading in practice can be described as a form of pre-loading, in which an axial pre-load of any given value can be imposed by means of springs. The arrangement illustrated is by the same manufacturer, and is one that is extensively used for high-speed internal grinding spindles ; such an arrangement is almost of necessity for very sensitive work.

It will be noted that the bearing arrangement at each end of the spindle consists of two single-row, double-purpose bearings, paired up for mounting back to face (i.e., thrust faces in the same direction). These bearings are manufactured to ultra close limits of accuracy, and in addition to sharing the journal loads the two bearings in each pair will share the thrust load in reasonably close proportions. Oil is fed to the bearings by means of a wick feed, whilst the labyrinth arrangement shown adequately protects the bearings against the ingress of foreign matter, etc.

The advantages offered by the use of accurate ball and roller bearings with their anti-friction efficiency and quietness of running, have greatly increased their application to machine tools, and in the majority of such machines they are regarded in the designs as standard for the most sensitive of machine tools.

Some Metallurgical Aspects Contributing to Development in Machine-Tool Design

The progress in machine-tool design is associated with higher operating speeds, and the more exacting demands made upon the machines in service and metallurgical

Fig. 10.—The Churchill Model " BY " plain grinder.
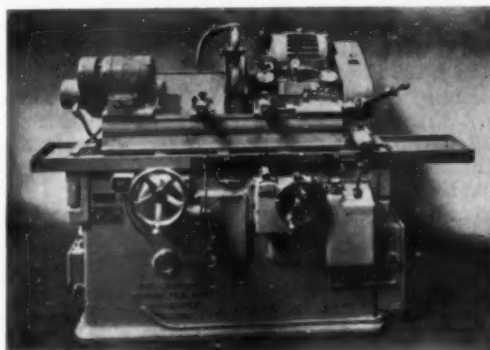
progress has contributed, in no small degree, to the advancement made. For structural purposes the machine-tool designer has been able to draw upon a wider range of materials than formerly, and in order to obtain the requisite degree of rigidity combined with strength and fatigue-resisting properties, he has made greater use of alloy steels
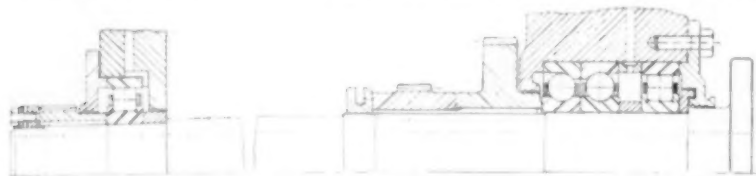

Fig. 12.—Arrangement of ball- and roller-bearing lathe headstock.

and alloy cast irons ; improvements in non-ferrous alloys have also been of great assistance to him.

Owing to the useful combinations of properties obtainable with nickel-alloy steels, with or without other alloying elements, the last few years have seen their almost universal adoption for the highly stressed components, such as gearbox gears and shafts, spindles and crankshafts. The
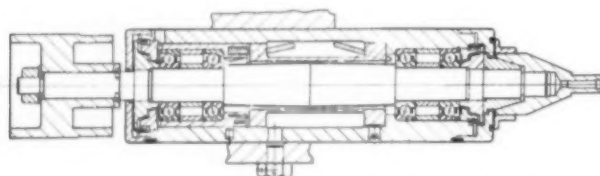

Fig. 13.—Arrangement of ball-bearing grinding spindle.

steels employed are either case-hardened or direct-hardened, according to the particular requirements, and are covered by B.S.I. specifications. When it is pointed out that the tensile strengths which are available fall within the limits 40–95 and 45–120 tons per sq. in. respectively, it will be appreciated that a wide range of properties is available to meet the varying conditions which obtain in service.

The addition of nickel with or without other elements to cast iron has provided another range of valuable materials for the machine-tool builder. Leading makers have adopted the low-nickel grey cast iron for heavy components, such as beds and slides. This type of iron has great uniformity with a high degree of resistance to wear. Its use in components such as those mentioned above ensures an improvement in service life and in maintenance of accuracy, as compared with those made in the ordinary type of grey cast iron.

For automatic machines, where greater resistance to wear is required, slides and top beds are made in a 3% nickel cast iron hardened and tempered to 280 Brinell. A similar type of iron has proved advantageous for bushes and other smaller components. For resistance to the most intense abrasive wear, hard "as cast" irons are available for parts such as centreless grinder rests, where preparation of the castings involves only grinding operations.

The high strength now available by the use of the specially processed high-duty " Ni-Tensyl-Iron " makes possible considerable improvements in the design of large gearwheels, and also enables weight reduction to be effected in large moving parts of machine tools.

Many of the best known light aluminium alloys, which by suitable modifications in heat-treatment provide tensile strengths up to, and over, 30 tons per sq. in., are valuable in reducing the weight of rapidly reciprocating components and in thereby facilitating an increase of operating speed without overloading the bearings.

It has only been possible to refer briefly to some aspects of machine-tool design, which have contributed to progress in the industry, and to give a few examples to indicate that the British machine-tool industry is active and progressive and fully alive to the need for consistent development. At the present time the call upon its resources, because of war conditions, is abnormal, but on the return to normal times the high excellence of its products should place it in a better position for home and export trade than it has previously experienced.

A Metallurgical Survey of Machine Cutting Tools

By H. W. Pinder

Research Laboratories, Wm. Jessop and Sons Ltd., and J. J. Saville and Co. Ltd., Sheffield.

The production of consistently high quality machine cutting tools can only be achieved by carefully planned and sustained technical control, but in this survey are briefly discussed factors which govern the casting of a tool steel ingot, its hot working and subsequent heat-treatment. Metallurgical factors in machining are also discussed, particular reference being made to high-speed steels and carbide tools.

THE production of machine tools is necessarily a highly specialised part of the steel industry, and at no time has there been such a great demand for a consistently high quality product as there is to-day. Such a high standard is likely to be achieved and maintained only by a carefully planned and sustained technical control. This should commence by the selection of the best bases and raw materials available and continue through the melting, hot working, and heat-treatment processes to the finished tool.

There are many different classes of steels and alloys making up the contingent from which the various machine tools are made, and typical analyses are shown in the accompanying table.

Considering first the production of the steel, factors to be borne in mind are those which govern the casting of

an ingot having (1) a minimum of ingotism and segregation consistent with soundness, (2) freedom from excessive amounts of deoxidation products, (3) smooth dense ingot skins. Steel most likely to meet the qualities enumerated above is readily produced in the electric arc furnace, the steel being finished under a reducing slag. In addition, a measure of refining can be conveniently carried out should the necessity arise. Other satisfactory methods of melting are afforded by the coke and electric crucible processes, but when these methods are employed either a remelting operation using high quality scrap is contemplated, or high quality bases must be used as no measure of refining is usually attempted in the manufacture of of such steels made by these methods.

Having produced clean sound ingots, carefully controlled cogging, forging, and rolling operations within specified

—	C.	Mn.	Si.	S.	P.	Cr.	W.	V.	Mo.	Co.
Roughing and semi-finishing tools	0·75	0·35	0·21	0·018	0·20	4·1	18·9	1·3	—	—
	0·78	0·37	0·23	0·019	0·21	4·2	19·7	1·2	—	10·1
	0·72	0·36	0·25	0·018	0·20	4·1	18·6	1·1	0·5	1·1
Finishing tools	1·6	0·30	0·31	0·018	0·02	0·7	6·1	1·2	—	—
	1·5	0·28	0·30	0·018	0·022	1·3	8·9	—	—	—

Roughing and finishing carbide tools ...
- Tungsten carbides + cobalt.
- Tungsten and titanium carbide + cobalt.
- Tungsten, titanium, and tantalum carbides + cobalt.

temperature ranges must be carried out in order to produce a dense and satisfactory homogeneous structure. Careful checking and inspection after pickling at intermediate stages of hot working followed by grinding faulty areas should the necessity arise, will save much scrap in the finished bars. Final annealing should put the material into a condition almost free from stress, and produce within the steel a suitable condition whereby it can be readily machined and subsequently successfully heat-treated.

Unfortunately, it is in heat-treatment and subsequent subsidiary operations such as grinding, where a good many tools are either partially spoilt, or ruined. For optimum hardening, the importance of commencing with the correctly annealed structure cannot be over-estimated. The annealed micro structure should consist of complex carbide distributed as uniformly as is practical throughout a medium grained ferrite ground mass, as shown in Fig. 1. The factors governing an annealed structure of this type are the finishing forging temperatures of the bars or blanks, the annealing temperature, and the rate of cooling. Keeping in mind the types of steel shown in the table, it is to be noted that a coarse grain resulting from a high finishing forging temperature may often persist and its effect noticed in the finally heat-treated tool. The annealing temperature and the rate of cooling on the other hand determine the size, shape, and distribution of the carbide, and this in turn is important because of the influence produced on the grain size of the finished heat-treated tool. On the one hand too many rather large carbide particles tend to inhibit grain growth, but on the other hand they may prevent the tool hardening to its full capacity. However skilfully the heat-treatment operations are carried out there is likely to be serious lack of efficiency in the finished tools, if the pyrometric control is not checked regularly. Checking should be carried out thoroughly at least once a week.

One of the greatest difficulties until recent times was the control of decarburisation during preheating and hardening. To-day, however, by the installation of modern equipment such as salt baths and atmosphere controlled furnaces, this difficulty can be eliminated. It must not be concluded, however, that such up-to-date equipment does not require skilful manipulation. On the contrary, care is continually needed to maintain the correct conditions for given tool compositions. Tools for finishing operations (see table), such as final cuts in gun barrel rifling where only one- or two-thousandths of an inch of metal is removed, are satisfactorily hardened by heating uniformly to 820° C. and quenching in aired water (20/25° C.). Such tools are then intensely hard (68 Rc) and in a high state of stress. Hence if cracking is to be avoided they should be tempered immediately by placing in a warm tempering bath, raising the temperature slowly to 180/200° C., and soaking thoroughly. After removing from the tempering bath they should be air-cooled. The hardness is not reduced by this low tempering temperature and after careful grinding such tools should maintain an excellent edge during light fast finishing cuts.

The heat-treatment of high-speed steels is rather more complicated and is rendered more so by the infinite number of intricately designed tools in service to-day. Probably the simplest tool to treat is the toolbit, but many of the complex hobs, reamers, and broaches call for a special technique and a high degree of skill and experience.

To such tools is added the large range of form tools where no grinding after heat-treatment is allowed. Such shapes and sizes raise additional problems such as greater susceptibility to cracking and/or distortion. There are many factors which cause distortion in a finished tool. If a complicated tool has been heavily machined it is
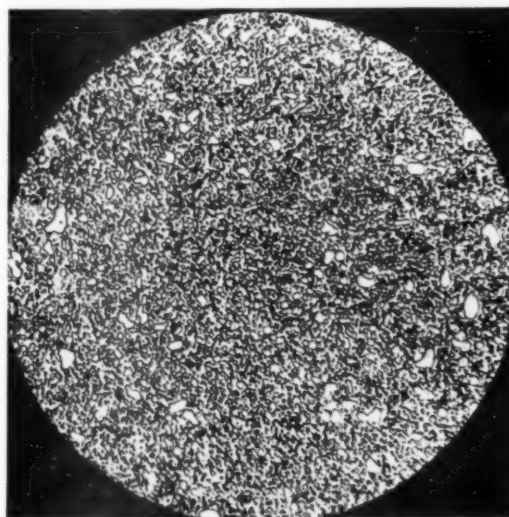

Fig. 1.—Annealed micro-structure of tool steel showing the uniform distribution desired of the complex carbide throughout a medium grained ferrite ground mass. × 500.

advisable to re-anneal by heating slowly to 750° C. followed by furnace cooling before attempting to harden. Furthermore, distortion in hardening can be minimised by flashing in oil until black and then cooling in still air. Where a reasonable grinding tolerance is allowed the tool could be cooled in still air from the hardening furnace, but should there be no grinding allowance flashing in oil until the tool is black prevents decarburisation by air when cooling through the high temperature range.

Where comparatively long and slender tools are being hardened they can be flashed in oil taking care to maintain them in a vertical position, removed from the oil, and should they be bent, straightened at a black heat while the tool is still in the austenitic condition. Cracking is reduced to a minimum in all tools providing they are taken from the cooling media when hand warm and placed in the tempering furnace at a low heat of 250° C. The tools should be allowed to equalise at this temperature and then raised steadily to a temperature of 590° C. If the tools are placed in the furnace above 450° C. there is a danger of cracking, for above this temperature quenched high-speed steel expands suddenly. It is also important to see that sharp changes in section are not under-cut and that wherever possible sharp angles are slightly rounded.

Metallurgical Factors in Machining

The properties desirable in a cutting material are broadly as follows :—

1. Resistance to wear at red heat.
2. Hardness or strength at red heat.
3. Ductility at red heat.
4. High thermal conductivity.

Up to the present no one appears to have been successful in combining all the desirable properties so as to create the ideal material for all applications of cutting. In a cutting operation the tool must rupture the material being machined, which means locally over-stressing it to the point of breaking, but without damage to the edge of the tool itself. Such an operation creates very high compressive stresses which can be relieved only by the slipping away of the ruptured material. As the operation is continuous and in the majority of cases long chips are formed, no relief is obtained by the edge of the tool and so, to the burden of stress which the tool is called upon to bear, that of wear is added. An equivalent to a relief of stress on the cutting tool, however, would be afforded by a high rate of heat conductivity, as the tool would work at a lower temperature thereby. When heavy broken chips are formed the tool is called upon to perform a discontinuous series of ruptures by shear and under these circumstances may fail very readily by shock.

Having given a brief outline of the properties desirable in a cutting tool, what are the available materials ? Steels used in finishing are satisfactory only for that purpose because they work at fine feeds with extremely shallow depths of cut, and the edges of the tool never reach anything like a red heat. If such materials were used for removing more than a few thousandths of an inch they would fall rapidly as the hardness of these tools begins to fall away when heated for any length of time above 300° C.

High-Speed Steel

The most universal cutting material is high speed steel with its various modified analyses. Assuming a sound well-forged tool, its performance depends on the heat-treatment to which it has been subjected. High-speed steels usually fail by wear resulting in a cupping effect, which in turn increases the top rake so that the cutting edge is weakened in section, and easily over-heated. Another cause of failure is over-loading by shock stresses which in most cases result from abuse or vibration. Other causes of failure may be entirely due to wrong tool design, but this should be most infrequent unless the conditions under which the tool functions are chiefly experimental.

It should be remembered that the first necessity in obtaining the maximum hot hardness from a high-speed steel tool is to harden it from the highest temperature possible without causing any degree of fusion. Subsequent tempering at 580/598° C. once, twice, or even three times according to the composition will develop the maximum hardness of the tool. Such a condition is probably the best for continuous cutting on good machines, and carefully produced tool design. For many purposes, however, such as milling or gear cutting this condition would be too brittle, and a reduced hardness and increased ductility could be readily obtained by reducing the hardening temperature, or alternatively tempering at lower temperatures between 400 and 450° C. The addition of cobalt to high-speed steel has the effect of increasing the red hardness range, and wear resistance without reducing the ductility. From this it can be seen that a more efficient high-speed steel is the result. Quantities up to 18% are added and although higher hardening temperatures are required, i.e., 1,340° C. to 1,360° C. and they decarburise more easily than the straight 18% tungsten steels, the advent of the salt bath and controlled atmosphere furnaces have cancelled out these disadvantages. Cobalt high-speed steels are particularly recommended for machining heat-treated steels, scaled ingots and sand castings.

Other cutting alloys which have come into their own during recent years are the cast and cemented carbides, and there are no doubts as to their commercial applicability. The cast carbides depend for their properties on a highly controlled casting technique which has resulted in the production of a very fine grained tool, and there is no disputing their superiority in cutting certain materials.

Carbide Tools

Of much greater significance, however, are the performances of the cemented carbide tools. Initially, their success was proved in the machining of cast iron, but, to-day, they are available in many grades and under the correct conditions their scope has been extended to machining many types of castings and heat-treated steels. In addition they can be used to give excellent machined finishes to the work. The application of carbide tools requires a different technique from that of high-speed tools. Although they are intensely hard and resist wear at elevated temperatures to a much greater degree than high-speed steel tools, they have a low resistance to shock, and low shear and tensile strength. They cannot be applied on old machinery as vibration destroys the cutting edge, and if put on work with heavy feed at slow speeds they invariably fail prematurely. As a general rule the best results are obtained with fine feeds and high-cutting speeds.

Much of the success of the application of cemented carbide tools has been due to extensive research carried out over long periods. The first cemented carbide tool was a single bonded tungsten carbide. This compound is produced by heating finely divided tungsten powder and carbon in a reducing atmosphere for three to four hours between 1,500/1,550° C. The carbide is then broken down and fine cobalt metal is added and the two components thoroughly mixed in the wet ball mills. By this means the carbide becomes mechanically coated with a thin layer of cobalt metal which facilitates bonding in the primary sintering operation. The latter operation is preceeded by cold-pressing the mixture into desirable shapes, and the initial sintering is carried out to increase their strength so that the various shapes can be ground very near to their final sizes. Allowance should be made, however, for slight shrinkage when sintering at the final temperature of 1,400/1,500° C.

Final sintering is carried out in a reducing atmosphere for periods ranging from 20 minutes to 2 hours depending on the composition, size, and properties desired in the final cutting alloy. The rate of cooling from sintering can also appreciably affect the properties of the cemented carbides. Rapid cooling from sintering prevents the tendency of the material to return to the stable condition, inhibits the formation of graphite which has an embrittling effect, and results in a harder and more dense product.

The chief reason for the failure of the mono cemented tungsten carbide when cutting steel was the cavitation caused by the continual pressure of the cuttings immediately behind the cutting edge. Such an effect weakens the cutting edge to such an extent that failure is inevitable. The addition of titanium or tantalum which form very hard carbides to the tungsten carbide mix, has resulted in reducing the tendency of the tool to cavitate just behind the cutting edge, so much so that steel can be machined now as successfully as cast iron.

One point to remember in the application of the harder mixed carbides is their reduced resistance to shock, which means that their application will be successful only if used in conjunction with modern machines possessing a rigid construction. Given satisfactory conditions then, the cemented carbide tools have an extensive range of application and, along with the various high-speed steels, should cover both comprehensively and economically the whole field of machining.

The Oxygen/Hydrogen/Molten-Iron System

By Dr.-Ing. Henry Lepp (Dives-sur-Mer, France)

In this study the author attempts to demonstrate the co-existence in molten iron of the oxide (FeO) and of absorbed hydrogen (hydride), his calculations being based on experimental data already published. The paper is to be presented at the May, 1940, meeting of the Iron and Steel Institute, an advance copy of which is reproduced in this article.

SINCE the classic researches of Sainte-Claire Deville,[1] numerous investigations have been made into the reaction of water-vapour with iron, and the experimental results obtained may now be said to show very good agreement.

Up to the melting point of iron, in particular, the variation of the equilibrium constant of the reaction :
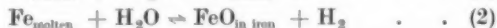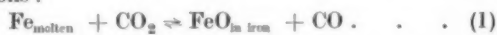
$$Fe + H_2O \rightleftharpoons FeO + H_2$$
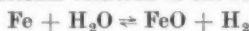
in terms of temperature is known with a fair degree of accuracy.

This is not true for higher temperatures, however, since fewer researches have been carried out on the equilibrium of the system molten-iron/water-vapour. The constant of the reaction has usually been defined by the expression :

$$K = \frac{(H_2)}{(H_2O)} = \frac{(p_{H_2})}{(p_{H_2O})},$$

that is, by the composition of the gas phases above the metal (the ratio p_{H_2}/p_{H_2O}), thus neglecting the content of absorbed hydrogen and of oxide (FeO) in the metal.

It is only in recent years that the significance of the reactions :

$$Fe_{molten} + CO_2 \rightleftharpoons FeO_{in\ iron} + CO \quad . \quad . \quad (1)$$
$$Fe_{molten} + H_2O \rightleftharpoons FeO_{in\ iron} + H_2 \quad . \quad . \quad (2)$$

has been appreciated in their bearing on steel manufacture (formation and nature of the flakes, occluded gases, the influence of hydrogen on the properties, etc.) and that they have been further investigated.

Owing to the fact that these workers were able to utilise improved methods and apparatus, the results of their experiments agree very satisfactorily with each other, while at the same time spectroscopic analysis has enabled the thermodynamics of these reactions to be placed on an increasingly accurate basis and in this way has facilitated their study.[7]

Chipman and Samarin have defined the constant of the reaction :
$$FeO_{in\ iron} + H_2 \rightleftharpoons Fe_{molten} + H_2O$$
by :
$$K_1 = \frac{(H_2O)}{(H_2)(\%\ O)} \text{ and } K = \frac{(H_2O)}{(H_2)(\%\ FeO)}.$$

Obviously the equilibrium constant obtained by these writers is much more accurate, and gives a much more complete idea of the actual mechanism of the reaction than the constant expressed by the formula :

$$K = \frac{(H_2)}{(H_2O)}.$$

In the above work, however, the absorption of hydrogen by the metal was neglected, and only the concentration of the hydrogen above the metal was considered.

This interpretation is not accurate, since the analysis of the gases extracted from the steel reveals the co-existence of oxygen and hydrogen. Moreover, the researches of Allen and Hewitt[8] and of the present author[9] have shown the simultaneous presence of oxygen and hydrogen, or, rather, of the oxide and the hydride, in molten copper and nickel (see Fig. 1).
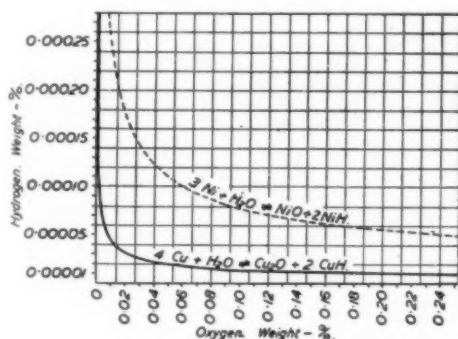

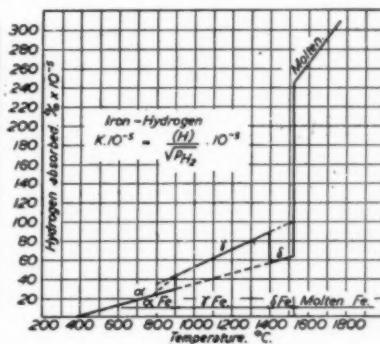Fig. 1.—Co-existence of Oxide and Hydride in Copper and Nickel.

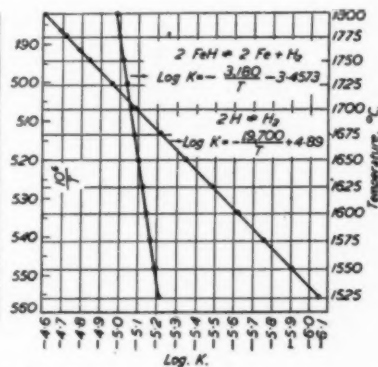Fig. 2.—Absorption of Hydrogen by Iron in dependence on the temperature.

Fig. 3.—Equilibrium between Iron and Molecular and Atomic Hydrogen.

Special mention may be made of the quantitative researches of Vacher and Hamilton[2] and of Vacher[3] in connection with the reactions (1) and (2) above, and it is these that will be specially dealt with in the course of this paper. The author would also mention the remarkable researches of Chipman,[4] Fontana and Chipman[5] and Chipman and Samarin.[6]

The experimental results agree very well with the thermodynamical calculations based on a study of the reactions :

$$2Cu + H_2O \rightleftharpoons Cu_2O + 2H \text{ (hydrides)},$$
$$Ni + H_2O \rightleftharpoons NiO + 2H \text{ (hydrides)}.$$
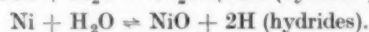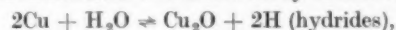
This paper, which is based on experimental results, therefore attempts to show that this co-existence of oxygen and hydrogen exists in molten iron also.

The system molten-iron/hydrogen will be dealt with first.

1 Sainte-Claire Deville : *Comptes Rendus*, 1870, vol. 70, p. 1105 ; 1871, vol. 71 p. 30.

2 H. C. Vacher and E. H. Hamilton : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1931, vol. 95, p. 124.

3 H. C. Vacher : *Bureau of Standards Journal of Research*, 1933, vol. 11, p. 541.

4 J. Chipman : *Journal of the American Chemical Society*, 1933, vol. 55, p. 3131.

5 M. G. Fontana and J. Chipman : *Transactions of the American Society for Metals*, 1936, vol. 24, p. 313.

6 J. Chipman and A. M. Samarin : *American Institute of Mining and Metallurgical Engineers, Technological Paper No. 784* ; *Metals Technology*, Jan., 1937.

7 C. Schwartz and T. Koots : *Archiv für das Eisenhüttenwesen*, 1938, vol. 11, p. 527.

8 N. P. Allen and T. Hewitt : *Journal of the Institute of Metals*, 1933, vol. 51, p. 257

9 H Lepp : *Metal Industry*, 1935, vol. 47, Sept. 27, p. 315; Oct. 4, p. 341. Norwegian patent No. 56,408 (priority of Nov. 28, 1932). German patent No. 622,182 (Jan. 10, 1933). French patent No. 791,898 (priority of Aug. 15, 1932).

The fundamental researches of Sieverts, summarised in Fig. 2, have shown that the absorption obeys the law :

$$M = K_1 \sqrt{p},$$

where M = quantity of gas absorbed ; K_1 = characteristic constant for the gas/metal system considered, which also depends on the temperature ; p = gas pressure.

Expressed differently, this means that the amount of hydrogen absorbed by the iron is proportional to the square-root of the pressure.

The author has also been able to show[10] that Sieverts' law was only a specific instance of the law of mass-action, and that Sieverts' constant was equal to the square-root of the equilibrium constant of the gas/metal system :

$$K_1 = \sqrt{K},$$

where K_1 = Sieverts' constant, K = equilibrium constant.

In view of the fact, however, that Sieverts' law involves the dissociation of the molecule into atoms, the absorption of hydrogen by iron may be represented by the reaction :

$$2Fe + H_2 \rightleftharpoons 2FeH \text{ (hydride)} \quad . \quad . \quad (3)$$
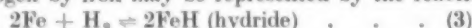
and the equilibrium constant of the reaction will then be given by :

$$K = \frac{(FeH)^2}{(Fe)^2(H_2)} = \frac{(FeH)^2}{(pH_2)}$$

and

$$(FeH) = \sqrt{K} \sqrt{pH_2} \text{ (Sieverts' law)},$$

where $\sqrt{K}$ = Sieverts' constant.

Since Sieverts' constant is known for the system iron-hydrogen (see Fig. 2), it is a simple matter to deduce from it the equilibrium constant of reaction (3).

$$\log K_p = -\frac{3,180}{T} - 3 \cdot 4573,$$

and the variation of the free energy :

$$\Delta F_1 = +14,542 \cdot 4 + 15 \cdot 802 \, T.$$

The absorption of hydrogen by iron is an endothermic phenomenon which probably takes place with the formation of a hydride of iron, with a heat of reaction equal to $-14 \cdot 5$ kg. cal. (gross figure) :

$$2Fe + H_2 \rightleftharpoons 2FeH - 14 \cdot 5 \text{ kg. cal.}$$
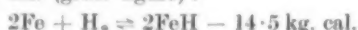
The heat of formation of FeH is therefore $-7 \cdot 2$ kg. cal. (approximately).

A comparison of the constant of thermal dissociation of hydrogen given by Langmuir's equation[11] :

$$\log K = \log \frac{(pH)^2}{(pH_2)} = -\frac{19,700}{T} + 4 \cdot 89,$$

with the constant of the absorption of hydrogen by iron :

$$\log K_p = \log \frac{(FeH)^2}{(pH_2)} = -\frac{3,180}{T} - 3 \cdot 4573$$

shows that, above roughly $1,708°$ C., according to Langmuir's equation, atomic hydrogen will co-exist in the gas phase with the molten iron, without, however, being absorbed by the metal (see Fig. 3).

This point requires careful verification, since it is possible that the absorption of hydrogen by molten iron has not been studied very accurately at these high temperatures.

The other extreme case—viz., the system oxygen/molten-iron, will now be examined.

The oxidation of molten iron by oxygen is governed by the reaction :

$$Fe + \tfrac{1}{2}O_2 \rightleftharpoons FeO \text{ (in the iron).}$$

According to Chipman and Samarin[6] who obtained good agreement with the results of Schenck[12] on the dissociation of FeO in molten iron, the equilibrium constant of this reaction is given by the equation :

$$\log K = +\frac{2,960 \cdot 87}{T} + 2 \cdot 449166,$$

and the variation of free energy by :

$$\Delta F = -13,540 - 11 \cdot 20 \, T.$$

10 H. Lepp : *Bulletin de l'Association Technique de Fonderie*, 1937, vol. 11, Mar., p. 84.
11 J. Langmuir : *Zeitschrift für Elektrochemie*, 1917, vol. 23, p. 233.
12 H. Schenck : " Physikalische Chemie der Eisenhüttenprozesse," vol. 1, p. 137. Berlin, 1932 ; Verlag von Julius Springer.

On the other hand, the solubility of oxygen, or, rather, of FeO, in molten iron has been determined by Körber and Oelsen,[13] and their figures are equally valid (see Fig. 4).
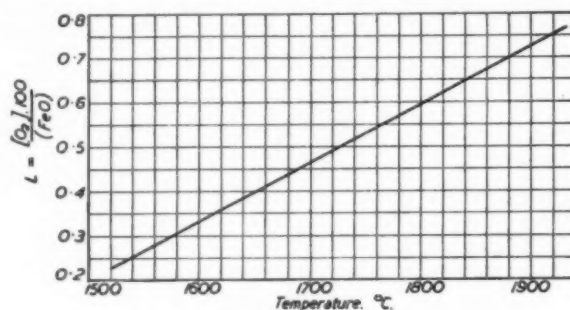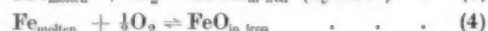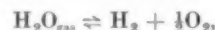

Fig. 4.—Solubility of Oxygen (L) in Iron.

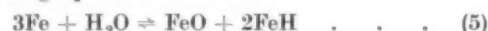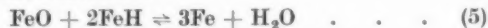By combining the two extreme cases that have just been discussed—viz., the reactions :

$$2Fe_{molten} + H_2 \rightleftharpoons 2FeH_{in iron} \text{ (hydride)} \quad . \quad (3)$$
$$Fe_{molten} + \tfrac{1}{2}O_2 \rightleftharpoons FeO_{in iron} \quad . \quad . \quad . \quad (4)$$

with the thermal-dissociation reaction of water :

$$H_2O_{gas} \rightleftharpoons H_2 + \tfrac{1}{2}O_2,$$

the following equation is derived :

$$3Fe + H_2O \rightleftharpoons FeO + 2FeH \quad . \quad . \quad . \quad (5)$$

and the constant :

$$K = \frac{(FeO)(FeH)^2}{(Fe)^3(H_2O)}$$

which defines the chemical equilibrium of the system formed by water-vapour and molten iron. At the same time, the thermo-dynamic analysis enables the value of the equilibrium constant of equation (5) to be deduced from the foregoing arguments. It is :

$$\log K = -\frac{13,383 \cdot 5}{T} + 2 \cdot 04857,$$

while the variation of the free energy becomes :

$$\Delta F = +61,202 \cdot 4 - 9 \cdot 368 \, T.$$

There are, however, no experimental data by which this equation can be verified, because researches of this kind have been carried out only for copper and nickel (Allen and Hewitt[8] and the author[9]). For this reason, a slightly different method must be adopted for calculating the co-existence of hydrogen and oxygen in iron in terms of known experimental data.

It has previously been stated that Chipman and Samarin had studied the reaction :

$$FeO_{in iron} + H_2 \rightleftharpoons Fe_{molten} + H_2O_{gas} \quad . \quad . \quad (6)$$

between $1,600°$ and $1,770°$ C., and that they had experimentally determined the value of the ratio H_2O/H_2 in the gas phase above the molten iron, as well as the corresponding percentage of FeO dissolved in the metal.

From this they deduced the equilibrium constant :

$$K = \frac{(H_2O)}{(H_2)(\% FeO)}$$

as :

$$\log K = +\frac{10,200}{T} - 5 \cdot 50,$$

and the variation of the free energy as :

$$\Delta F = -46,660 + 25 \cdot 17 \, T.$$

In this investigation, the absorption of hydrogen by the metal was ignored.

However, by combining equations (5) and (6) it is possible to work out the figure for the simultaneous presence of

13 F. Körber and W. Oelsen : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 181.

hydrogen and oxygen, or, rather, for the oxide and hydride, absorbed by the metal.

It should be noted that the equilibrium constant of one of these equations has been determined directly by means of experimental data, while the other has been calculated from thermodynamic considerations, and also on known experimental and spectroscopic bases.
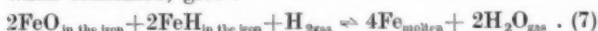
Thus the reactions :

$$FeO + 2FeH \rightleftharpoons 3Fe + H_2O \quad . \quad . \quad . \quad (5)$$
$$\Delta F = - 61,202 \cdot 4 + 9 \cdot 368\,T,$$

and :

$$FeO + H_2 \rightleftharpoons Fe + H_2O \quad . \quad . \quad . \quad (6)$$
$$\Delta F = - 46,660 + 25 \cdot 17\,T,$$

when combined, give :

$$2FeO_{\text{in the iron}} + 2FeH_{\text{in the iron}} + H_{2\,\text{gas}} \rightleftharpoons 4Fe_{\text{molten}} + 2H_2O_{\text{gas}} \; . \; (7)$$

with

$$K = \frac{(Fe)^4(H_2O)^2}{(FeO)^2(FeH)^2(H_2)}$$
$$\Delta F = - 107,862 \cdot 4 + 34 \cdot 538\,T \quad . \quad . \quad (7a)$$

and

$$\log K = + \frac{23,586 \cdot 82}{T} - 7 \cdot 5526 \quad . \quad . \quad (7b)$$

The thermodynamic verification of this equation with the help of the well-known reactions :

$$Fe + \tfrac{1}{2}O_2 \rightleftharpoons FeO,$$
$$2Fe + H_2 \rightleftharpoons 2FeH,$$
$$H_2 + \tfrac{1}{2}O_2 \rightleftharpoons H_2O,$$
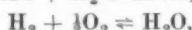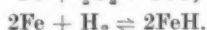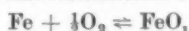
has led to this same equation (7b).

It is therefore equation (7) which best represents the mechanism of the reaction of water-vapour with molten iron, and enables the value of the ratio of the oxide to the hydride dissolved in the iron to be worked out from the experimental data previously published, since the only unknown quantity in this equation is the FeH concentration.

From Chipman's experimental results the author has calculated, for three different temperatures (1,525°, 1,600°, and 1,700° C.), the percentage of oxide in the iron in terms of the percentage of hydride ; the results are plotted in Fig. 5. It is interesting to note that these curves are identical in shape to those already obtained experimentally by Allen and Hewitt[8] and by the author[9] for copper and
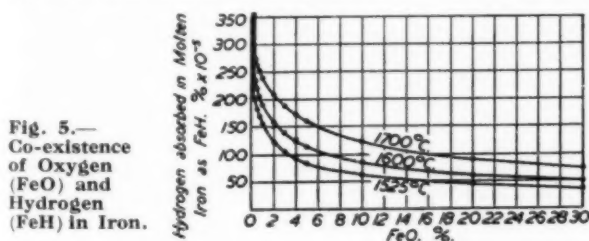
Fig. 5.— Co-existence of Oxygen (FeO) and Hydrogen (FeH) in Iron.

nickel, with this difference, however, that the hydride concentration is much higher for a given percentage of oxide.

Obviously, these curves have chiefly a theoretical interest, because in actual practice the solubility of oxide of iron is much below the value indicated by the curves. When the limits of solubility of FeO in iron are exceeded, the surplus oxide FeO passes over into the slag, so that the oxide FeO is distributed between the slag and the metal in a ratio defined by the coefficient of distribution :

$$L = \frac{FeO\ \text{in the metal}}{FeO\ \text{in the slag}},$$

which is a function of the temperature.

An examination of the curves representing equation (7), however, shows that about 20% of FeO is necessary to eliminate the excess of hydrogen absorbed by the metal ; further, practical experience demonstrates that the concentration of FeO in the slag is of this order.

The Evaluation of Time—Elongation— Curves according to Various Methods for the Determination of the Creep Strength, and a comparison of the Results with those of Long-Time Tests.

THE creep strength of a molybdenum-copper steel and of a chrome-molybdenum steel has been determined by twelve different methods of evaluation on uncovered, as well as nickel-plated, test-pieces in a salt-bath and in an air-furnace. The experiments in the air-furnace can be considered the more reliable because of the factor of nitrogen penetration when using a salt-bath.

The results of the investigations by means of the air-furnace are illustrated by the reproduced graph. The first nine results are scattered for both steels in limits of only ± 2 kilogs./mm.² (1·27 tons/sq. in.). These are the three methods of the Kaiser-Wilhelm-Institute at Düsseldorf, the German standard method DVM, the methods of Siebel-Ulrich, of Turetzek-Sauerwald, the Swiss standard method, the method of the National Physical Laboratory (N.P.L.) in Teddington, and the American method of a 1% elongation in 10,000 hours. Similar results could be obtained with the salt-bath for covered and uncovered test-pieces by using the first, second, fourth, fifth and seventh of those nine methods.
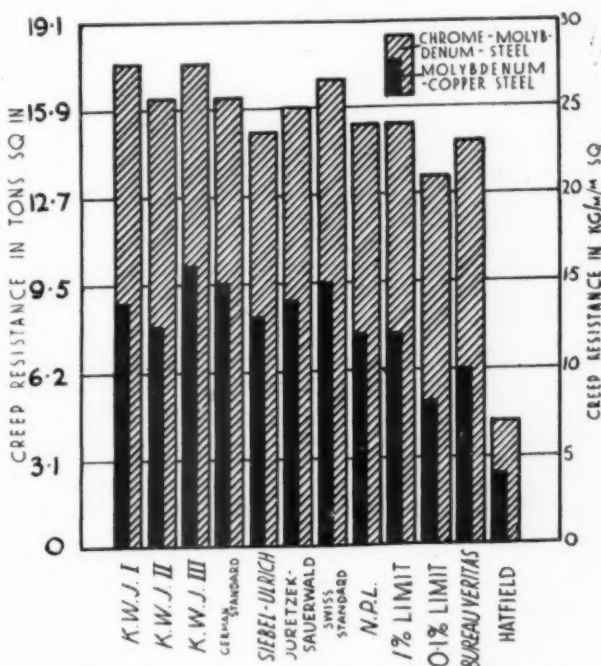
Creep resistance of test pieces as determined in the air furnace by different methods.

The three other methods, however—the American 0·1% limit, the French method of the Bureau Veritas, and the Hatfield method,—gave lower figures in all cases. It is obvious, as is confirmed by a more-detailed examination of the experimental suggestions, that these methods have been developed for conditions quite different from those of the first nine methods, which give, in particular, a prediction of the fracture of the test-piece, which means a limit that is outside the conditions obtaining in the last three methods.

Notched bar impact tests and investigations of the structure before and after the experiments have shown that, even after a load of 1,000 hours' duration, no change of the steels, and especially no brittleness, has taken place.

Anton Pomp and Alfred Krisch. Mitteilungen des Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf. Vol. XX. No. 19.

United States Aluminium Industry in 1939

A large increase in demand for aluminium in 1939 was caused by national preparations for defence and by the European war, which contributed to the largest production on record.

VIRGIN aluminium production in the United States last year was the largest on record. According to the Bureau of Mines, United States Department of the Interior, the 1939 peak output of new aluminium amounted to 146,000 tons, valued at $64,600,000, compared with 128,072 tons, valued at $56,659,000 in 1938. Production in 1939 was 14% greater than 1938, and exceeded the previous peak reached in 1937 by 12%. Despite the drought, which curtailed hydro-electric power development in the South, the reduction plant at Alcoa, Tennessee, produced more metal than the plant at Massena, New York. Of the total output, 41% was made at Alcoa, Tennessee ; 35% at Massena, New York ; 13% at Badin, North Carolina ; and 11% at Niagara Falls, New York.

The large increase in demand for the light, but strong, metal was caused by national preparations for defence and by the European war. In 1939 the aircraft industry consumed twice the amount of aluminium that it did in 1937, the previous record year. Other industries also continued to be larger users of aluminium. Withdrawals from producers' stocks in 1939 totalled 28,000 tons, compared with an addition to stocks of 50,400 tons in 1938. Notwithstanding the world-wide cry for aluminium, the domestic price for the metal remained unchanged throughout 1939. The Aluminium Company of America announced that there would be no increase in the basic ingot price during the first quarter of 1940. War-time needs caused the largest exportation of aluminium from the United States in history. Exports of crude and semi-crude aluminium totalled 33,067 tons, and exceeded the previous peak reached in 1918 (10,774 tons) by 207%. In the middle of December, 1939, the Government asked that the moral embargo apply on aluminium exports.

Imports of aluminium in ingot, scrap, alloy, etc., into the United States increased from 7,817 tons, valued at $2,430,828 in 1938, to 12,527 tons, valued at $3,251,484, in 1939 ; exports increased from 4,317 tons, valued at $1,860,796, to 25,533 tons, valued at $11,693,276. Of the 1939 import figures above, scrap aluminium comprised 4,505 tons, valued at $760,913, and exports comprised 420 tons, valued at $160,283. Imports of plates, sheets, bars, rods, etc., increased from 102 tons, valued at $60,566, in 1938 to 273 tons, valued at $133,548, in 1939 ; exports increased from 1,312 tons, valued at $2,050,995, to 7,580 tons, valued at $9,178,275. Imports of tubes, powder, foil, utensils, and other manufactured products declined from $1,572,256 to $1,381,147 ; exports increased from $1,572,256 to $2,760,944. Of the 1939 foreign trade in ingot, scrap and alloy, imports were chiefly from Canada, the United Kingdom, France, Norway and Switzerland, and exports were chiefly to the United Kingdom (8,875 tons), France (7,270 tons), Japan (4,360 tons), U.S.S.R. (1,600 tons), Belgium (1,240 tons), and Germany (500 tons). Plates, sheets, bars, etc., were imported largely from the United Kingdom and Switzerland, and exported largely to the United Kingdom, Canada, China and France.

The increasing demand for aluminium led the Aluminium Company of America to announce a $30,000,000 expansion programme, to begin in 1940, following a $26,000,000 development enterprise just recently completed. A new aluminium-reduction plant to be completed on or before January 1, 1941, at Vancouver, Washington, will cost approximately $18,000,000, and will be capable of producing 14,000 tons of new metal annually. This plant, first of its kind in the Western United States, will utilise alumina shipped from Mobile, Alabama, and power generated at the Government-owned Bonneville Dam in the Columbia River. Other major improvements by the Company will include : a bauxite plant in Paranam, Surinam (Dutch Guiana), with a capacity of 450,000 tons of bauxite annually; the acquisition of additional ore-carrying vessels by the Ocean Dominion Steamship Company to take care of increased ore shipments from South America ; additions at the Mobile, Alabama, alumina works ; improvements in the East St. Louis, Illinois, alumina works ; additions to the Alcoa, Tennessee, metal-producing plant ; improvements in the hydro-electric stations along the Little Tennessee River ; and increased and improved fabricating and laboratory facilities. Capacity of the Alcoa, Tennessee, aluminium-reduction plant will be increased approximately 20%, and the total capacity of all the Company's plants (including that at Vancouver) will exceed 178,600 tons of metal annually.

The large consumption of aluminium in the aircraft industry has resulted in the installation of new production equipment and the accumulation of stocks of standard aircraft products. A large hammer, weighing a million pounds, for forging propellors, crankcases, and landing gears was recently installed, and a large corrugating press for the manufacture of airplane wings and other aluminium products will shortly be in service.

The general advance in industrial activity during 1939 caused a wider application of aluminium in many old and new uses. The total mileage of aluminium cable, steel-reinforced, in the United States increased to 850,000 in 1939. More than 100,000 miles of cable was used in the rural electrification programme during the year, and over 1,000 miles of large-diameter cable was shipped to the Bonneville Dam project for use in the construction of 220,000-volt power lines. The quantity of aluminium used for truck bodies in 1939 was double that of 1938, and that used for windows, spandrels, and other architectural purposes was up 80%. The Criminal Courts building in New York City alone will require 500,000 lb. of architectural aluminium in 1940. Among the new buildings using aluminium architecturally are the last unit of Rockefeller Center, New York City, the office building of the Johnson Wax Co., Racine, Wisconsin, and the plant buildings of the Tennessee Valley Authority.

Further advances have been made, and more are expected, in the use of aluminium in the marine field, and as a structural material for trains that operate on railroads, subways, street railways and elevated railways, and for bus lines. Early in 1940 two new all-aluminium alloy streamlined trains will be put in service on the Missouri Pacific Railroad's St. Louis-Kansas City-Omaha run. The new Union Pacific steam-electric locomotive has an almost all-aluminium cab, and five railroads have started equipping their locomotives with recently developed aluminium-alloy crosshead shoes. An all-aluminium subway car was introduced by New York's Brooklyn-Manhattan Transit Company in 1939. One 1940 order of General Motors includes the construction of 400 streamlined aluminium buses for the Greyhound Bus Co. The furniture for many of the new ships built in 1939 is made of aluminium.

New brazing methods, developed in 1939, will improve the manufacture of such products as refrigerator evaporators, tanks for outboard motors, etc. Brazing is expected to mean as much in the fabrication of aluminium alloys as welding did a number of years ago. The textile industry aluminised much of its equipment in 1939, several aluminium models of the iron lung for infantile paralysis cases were made available, and more aluminium was used in the construction of flood protection accessories. Among the more-recent applications of aluminium were the use of aluminium foil as locomotive-boiler insulation, and for adding brilliance to women's clothing and accessories ; of a single-purpose aluminium house paint ; and of aluminium-alloy automotive bearings.

Reviews of Current Literature

Chemical Spectroscopy

To those who are applying spectroscopic methods to the solution of chemical and metallurgical analytical problems, the appearance of this book will be very welcome. The author, who is Professor of Chemistry in the Ohio State University, deals with his subject under two principal sub-divisions—qualitative and quantitative analysis of the elements (a subject which is becoming of increasing interest to metallurgical chemists) and absorption spectra of organic and inorganic compounds. Professor Brode is chairman of the A.S.T.M. Sub-Committee on Apparatus and Equipment, and also of a Committee on the Application of Spectro-scopic Methods to Chemistry (National Research Council), and has previously made notable contributions to the literature on both emission and absorption spectroscopy.

The scope of the book is wide, including chapters on Infra-red and Raman Spectra, Theory and Description of Colour (including colorimetric applications) and Theory and Practice of Photography. The apparatus described and amply illustrated, covers the products of the principal optical instrument makers both in Europe as well as in the United States.

This is a reference and textbook of value, not only to students of applied spectroscopy, but to research workers in industry, as it givs a concise summary of the present position and scope of application of emission and absorption spectra to analytical problems. To those who are about to plan laboratories for control and research purposes, much valuable information will be found in Chapter XIV, which is devoted to the choice of equipment and the design and operation of a spectroscopic laboratory.

While the theoretical basis of spectroscopic methods receives adequate treatment, the greater part of the subject matter is eminently practical in character. Chapter XII, for example, gives a set of twelve laboratory experiments, based on a course in Chemical Spectroscopy instituted by the author in the Ohio State University.

The development of methods for quantitative analysis is traced, and a number of useful tables for qualitative and quantitative analysis are given. Those giving the persistent and principal lines of the elements are arranged in convenient form for quick reference. At the end of the book are 35 charts of adjacent portions of the iron spectrum with indicated line positions of other elements. A classified bibliography gives references to books and articles dealing in greater detail with the different aspects of the more general subject depicted by the author.

The printing and the style of presentation are both clear and pleasing, and the illustrations are well chosen.

By WALLACE R. BRODE. Published by John Wiley and Sons, Inc., New York; Chapman and Hall, Ltd., London. 1939. Medium 8vo. Pp. xi + 494 with 36 plates (one in colour), 333 figs., and numerous tables. Price 36s. net.

Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. 135

Iron and Steel Division

THIS 1939 volume of the Transactions of the American Institute of Mining and Metallurgical Engineering contains the Howe Memorial Lecture and a selection of the technical papers with their discussions, which were presented before the several meetings of the Iron and Steel Division during the past year. The Howe Memorial Lecture, entitled "Some Things We Don't Know about the Creeps of Metals," was given by Dr. H. W. Gillett, and was presented about the same time as the annual lecture, entitled "The Creep of Metals," before the Institute of Metal Division by Dr.

Daniel Hanson. This latter lecture is published in the current Institute of Metals Division volume (vol. 133), and the two lectures together summarise admirably the extent of current knowledge on this important subject.

In addition to the lecture there are 19 papers. Two of these deal with the solidification of rimming steel ingots; they are entitled "Mechanism of Solidification and Segregation in a Low-carbon Rimming-steel Ingot," by Anson Hayes and John Chipman, and "Solidification of Rimming-steel Ingots," by A. Hultgren and G. Phragmén, and contain a wealth of information of assistance to steelmakers in improving the quality of soft rimming steel. Further papers include "Reduction of Iron Ores under Pressure by Hydrogen," by Michael Tenenbaum and T. L. Joseph; "Induction Furnaces for Rotating Liquid Crucibles," by E. P. Barrett, W. F. Holbrook, and C. E. Wood; "Dendritic Structure of Some Alloy Steels," by Daniel J. Martin and James L. Martin; "Occlusion and Evolution of Hydrogen by Pure Iron," by George A. Moore and Donald P. Smith; "Structure of Iron after Compression," by Charles S. Barrett; "Structure of Iron after Drawing, Swaging, and Elongation in Tension," by C. S. Barrett and L. H. Levenson; "Magnetic Torque Studies of the Texture of Cold-rolled and of Recrystallised Iron-silicon Alloys," by Leo P. Tarasov; "Influence of Atmosphere and Pressure on Structure of Iron-carbon-silicon Alloys," by Alfred Boyles; "Kinetics of the Decomposition of Austenite at Constant Temperature," by J. B. Austin and R. L. Rickett; "Reaction Kinetics in Processes of Nucleation and Growth," by William A. Johnson and Robert F. Meel; "Phase Changes in $3 \cdot 5\%$ Nickel Steel in the Ac_1 Region," by I. N. Zavrine; "Chromium in Structural Steel," by Walter Crofts; "Surface Allotropic Transformation in Stainless Steel Induced by Polishing," by J. T. Burwell and J. Wulff; "Nature of Passivity in Stainless Steels and Other Alloys: I and II," by H. H. Ulilig and J. Wulff; "Thermal Expansion of Nickel-iron Alloys (Nickel from 30 to 70%)," by J. M. Lohr and Charles H. Hopkins; "Low-temperature Transformation in Iron-nickel-cobalt Alloys," by L. L. Wyman; and "Fracture of Steels at Elevated Temperatures after Prolonged Loading," by R. H. Thielemann and E. R. Parker.

Published by the American Institute of Mining and Metallurgical Engineers, 29, West 29th Street, New York, U.S.A.; price $5·00.

1939 Book of A.S.T.M. Standards

THIS book of standards, on which publication work has been in progress for several months, is nearly completed. It is published in three parts, instead of two parts as formerly, Part I dealing with ferrous and non-ferrous metals, Part II with non-metallic materials for constructional purposes, and Part III non-metallic materials for more general applications. Parts II and III have already been published and Part I will be available very soon. This book is the most important and valued publication of the American Society for Testing Materials and is widely used in all branches of American industry, involving the manufacture, purchase and use of engineering materials. The 1939 publication is of unusual significance because, for the first time, it contains all the Society's specifications, whether tentative or formal standards.

Formerly, the Society issued an annual book of tentative standards, with the book of standards published every three years. Now they are combined in a three-year publication, with extensive supplements, to keep the books up-to-date, to be issued in 1940 and 1941. Many of our readers will be interested in this publication, and while it is impossible to give an adequate review of the book in condensed form, the following brief statement regarding it will be helpful.

Part I contains 1,335 pages and provides, in their latest approved form, 298 specifications, tests, and definitions covering ferrous and non-ferrous metals. Some 178 of the

items pertain to ferrous metals, 105 to non-ferrous, and 15 are general testing methods applying to both. The following classes of materials are covered by one or more specifications, in some cases as many as 30 separate specifications applying to various types and grades of products :—

Ferrous Metals.—Structural and rivet steel ; boiler steel plates and rivets ; strip steel ; filler metal ; concrete reinforcement steel ; commercial bar steels ; steel rails and accessories ; spring steel and springs ; spring wire ; blooms, forgings and axles ; wheels and tyres ; castings ; tubes and pipes ; bolting materials ; corrosion-resisting alloys ; zinc-coated steel and iron articles ; electro-deposited coatings ; wrought iron ; pig iron and iron castings ; ferro-alloys ; magnetic properties ; general test methods.

Non-ferrous Metals.—Aluminium and aluminium alloys ; magnesium and magnesium alloys ; ingot and cathode copper ; copper and copper alloy castings ; copper and copper alloy bars, forgings, rods and shapes ; copper wire and cable ; copper and copper alloy pipe and tubes ; copper and copper alloy plate, sheet, and strip ; lead and lead alloys ; nickel and zinc ; solder metal ; bearing metal ; deoxidisers ; die-castings ; electrical-heating and electrical-resistance alloys ; general test methods.

Part II contains 1,250 pages and provides 351 standards and tentative standards covering widely used non-metallic materials of interest in construction or relating directly thereto. The general classes of materials covered include :—

Cement, lime and gypsum ; brick and structural tile ; concrete masonry units ; building stone and slate ; mortar for unit masonry ; fire tests ; refractories, fire brick ; glass and glass products ; pipe and drain tile ; concrete and concrete aggregates ; non-bituminous road materials ; bituminous road materials ; soils ; bituminous materials for roofing, damp-proofing and water-proofing ; bituminous saturated materials for roofing and water-proofing ; timber and timber preservatives ; paint, varnish, lacquer, and related products ; pigments ; drying oils and thinners ; varnish and varnish materials ; lacquer and lacquer materials ; paint tests, putty ; thermometers ; general test methods.

Part III contains 1,203 pages and provides 245 specifications for a range of standards in many fields where the Society's work has been of importance such as petroleum products, textiles, rubber, electrical insulation, coal and coke, etc. Specifications, tests and definitions are given on the following :—

Coal and coke ; petroleum products and lubricants ; electrical insulating materials—varnishes, moulded materials, plates, rods, oils, ceramic products, also electrical tests, insulating paper, and mica products ; plastics ; rubber products—general methods, hose and belting, gloves, matting and tape, wire and cable, and cement, sponge and hard rubber products ; textile materials—asbestos, cotton, jute, rayon, and wool ; paper and paper products ; soaps and other detergents ; naval stores ; water ; thermometers ; general test methods.

Each part contains a complete subject index and there are three tables of contents, designed to make the book of maximum utility. The first lists items under the general materials covered : following this is a table of contents giving a complete list of all the items in the part by numeric sequence. The third table covers by subject the tentative standards, which appear in the back portion of each part. These tentative specifications are proposed standards in widespread use throughout industry. Practically all the specifications and tests have been reset in the double-column format. This use of new type gave all the Society's committees an opportunity to review the items included and to incorporate a number of editorial improvements. It should be noted that this book of standards does not include the chemical analysis of metals as the Society continues the publication of its volume on this subject, which includes 19 methods covering 250 pages and is priced at $2·50, cloth ; $2, paper.

Copies of the Book of Standards can be obtained from the American Society for Testing Materials, 260, S. Broad Street, Philadelphia, Pa., U.S.A. Prices for any one part $8, any two parts $15, all three parts $22 : supplements for 1940 and 1941, any one part $3, any two parts $5, all three parts $7 ; these prices refer to cloth bound volumes, for half-leather binding prices for each part and each supplement are increased by $1.

The Quality of Coke

HEAT is an essential requirement in iron and steel manufacture ; it is necessary for both chemical and physical reasons, first to effect a reaction which enables iron to be extracted from its ores, and secondly, to convert the crude iron first produced to the various types of iron and steel which can be applied to the many purposes for which particular grades or types are suitable. To such an extent is heat necessary in iron and steel manufacture that fuel is probably the most important item in the cost of running an iron and steel works, it is not surprising, therefore, that considerable attention has been given to the economical use of the raw fuel consumed. It has long been recognised that the conversion of raw coal into coke enables the greatest use to be made of the coal and much research and experimental work has been carried out on blast-furnace coke. Several coke research committees are at work, but so far only the Midland Coke Research Committee has published the results of its work in book form. The first report of this Committee was published about the middle of 1930, and now the second report, with which we are concerned in this review, has recently been published.

Coupled with the proper treatment of the ore, the right kind of coke of the right size and properly screened is needed. The modern coke oven, employing high temperatures for carbonising, has proved more suitable than older designs for producing the type of blast-furnace coke necessary. The installation of coke-oven plants adjacent to blast-furnaces has effected further economies, but when steelworks are also incorporated on the same site full use can be made of the rich surplus gas of the coke ovens and also the blast-furnace gas, and very considerable economies are effected. In many works, so accurate is the balance between the total heat produced and that used in the manufacture of coke, pig iron and steel, that the only fuel used is the coal charged into the coke ovens.

The first report, entitled " Coke for Blast Furnaces," gave the results of work completed up to the end of 1929. The present report deals with work completed by the end of 1937, with an occasional summary, where it seemed essential, of work carried out subsequently. All the work reported has formed the subject of progress reports to the Committee, and some of it has subsequently been used in papers for the technical press. The authors have been able to demonstrate the influence of the composition of coal on the quality of the coke made from it, and to show the valuable effect of the presence of both durain and fusain. They have been able to define, fairly precisely, the advantages of blending with coke dust, but are still baffled by the inter-reactions which take place between one (bright) coal and another, and have been unable to draw more than tentative conclusions as to the value of blending two or more such coals in different proportions.

The book is divided into four parts, each of which is conveniently sub-divided into chapters. The first part includes four chapters and may be regarded as introductions to various aspects of the subject. From a practical point of view, Part II, which deals with the standards of a commercial coke, is probably the most important section. Here is discussed in separate chapters the size, structure, sampling and analysis, density and porosity, abradability, hardness, reactivity, and specification of coke. Part III deals with the formation of coke, and the authors build up their discussion from work on the composition, decomposition, softening and swelling, and the plasticity of coal ; the formation of semi-coke and of coke from semi-coke, the mechanism of coke formation, and the measurement of the swelling power of coal. Part IV is concerned with improving the quality of coke, which is considered under four main sub-titles—viz., the influence of the size and purity of the coal, the influence of the method of charging an oven, the influence of the rate of heating an oven, and the influence of blending the coal charge.

This report is not a textbook, but it can be regarded as a valuable work of reference on coke ; it is admirably

illustrated and excellently produced, and the Midland Coke Research Committee, as well as the authors, have made a very valuable contribution to the literature on this important subject.

By R. A. MOTT, D.Sc., F.I.C., and R. V. WHEELER, D.Sc., F.I.C., with a Foreword by W. J. BROOKE, chairman of the Midland Coke Research Committee; published by Messrs. Chapman and Hall, Ltd., 11, Henrietta Street, Covent Garden, London, W.C. 2; price 36s. net.

Iron and Steel To-day

THIS book has been written with the object of providing a simple and interesting account of the various processes used in the production of the wide range of iron and steel products, together with simple explanations of the reactions and reasons involved, and the author has fulfilled his object admirably. It is well produced and forms one of a series under the title of "The Pageant of Progress," edited by J. W. Bispham, O.B.E., M.A., B.Sc.

The book deals with wrought iron, pig iron, the iron foundry, the several steel-making processes, the casting of steel, the working of steel, tool steel, mechanical testing and heat-treatment, and grades of steel and their properties. The information it contains is presented in a popular form, and in such a clear and concise manner that even those well versed in the subject will find it of great interest, while those less familiar with the technical side of iron and steel will readily understand the fundamentals of manufacture as presented by the author.

As indicating the progress achieved, the author points out that it is a long step from the primitive furnaces of our early ancestors, producing a few pounds of metal, to our modern blast-furnaces, with an average world output of 90 million tons of pig iron per annum. Yet in India to-day where there are blast-furnaces giving an output of 1,000 tons per day, native tribes are still to be found making small quantities of iron in primitive furnaces. Many inventors who contributed to the development of the British iron and steel industry, and incidentally to the industry throughout the world, were neither engineers nor metallurgists in the narrow sense of the term, yet their discoveries are outstanding achievements in the history of iron and steel manufacture, and reference to these in some detail adds to the interest of the book.

All the principal methods of steel manufacture are described in a simple and interesting way, while principles are explained in a satisfactory manner without the use of scientific language. Various sections of the industry discussed in separate chapters are presented in an admirable manner, though in the tool-steel section more attention might have been given to electric tool steel. However, in the space of 190 pages, the author has contrived to give a surprisingly full account of the subject and to incorporate some excellent photographs of modern British plant. The book is both interesting and informative and the price is low.

By JOHN DEARDEN, B.Sc.; published by Oxford University Press, Amen House, Warwick Square, London, E.C. 4; price 4s. 6d. net.

Inconel

INCONEL is a corrosion-resisting alloy containing approximately 80% nickel, 12–14% chromium, balance mainly iron. Nickel contributes in high degree to its resistance to corrosion by a great many inorganic and organic compounds throughout a wide range of acidity and alkalinity. Chromium confers the ability to remain bright under exposure to sulphur compounds in the atmosphere or in other corrosives; it also provides resistance to oxidising atmospheres at elevated temperatures and to oxidising conditions in corrosive solutions.

In addition to its good resistance to corrosion, Inconel has a very desirable combination of high strength and workability, both hot and cold. Very useful ranges of tensile properties are available; in the annealed condition fabrication of the material is facilitated by reasonably low yield strength values of 11 to 18 tons per sq. in., with elongations of 55 to 35% in 2 in., while tensile strengths as high as 85 tons per sq. in. are obtainable in heavily cold-worked wire. Resistance to ordinary forms of corrosion and freedom from ageing or stress corrosion are maintained throughout the range from annealed to heavily cold-worked material. This alloy has the important property of being free from intergranular deterioration when subjected to high temperatures.

Inconel is being used for various important heat-resisting applications, notably aero exhaust manifolds, sheaths for electric-cooker elements and hot-plates. Owing to its corrosion- and tarnish-resisting properties it has been used for many types of food and chemical plant. A new publication giving full particulars of the properties, uses, and fabrication of this nickel-chromium-iron alloy has just been issued, copies of which may be obtained on application to Henry Wiggin and Co., Ltd., Thames House, Millbank, London, S.W. 1.

Definitions of Heat-Insulating Terms and Methods of Determining Thermal Conductivity and Solar Reflectivity

THE British Standards Institution has just issued British Standard Definitions of Heat Insulating Terms and Methods of Determining Thermal Conductivity and Solar Reflectivity, B.S. 874.

In 1936 the Building Divisional Council of the Institution appointed a committee for the purpose of preparing standard terms for expressing heat insulation and also methods of test for determining heat-insulating properties. The aim in the preparation of the Definitions and Symbols has been to put forward a consistent terminology which should conflict as little as possible with that in use in other countries, with a view to clearing up the present confusion in many of the terms used. In so far as the specification for the Measurement of Thermal Conductivity is concerned, the committee realised that in many cases thermal conductivity alone does not suffice to give complete information on the thermal behaviour of a structure. They therefore discussed the desirability of including specifications appropriate to various articles in this category, but were deterred from doing so, both on account of their incomplete knowledge of the relevant factors, and also because it was felt that thermal insulation is but one aspect of the design and performance of such articles; consequently, it is preferable to group together the various matters affecting any one article, in a specification devoted entirely to that article.

Copies of this Specification may be obtained from the British Standards Institution, Publications Department, 28, Victoria Street, London, S.W. 1, price 2s. each, 2s. 2d. post free.

Non-Ferrous Metals Control

IN pursuance of Regulations 55 and 98 of the Defence Regulations, 1939, the Minister of Supply has issued the Control of Non-Ferrous Metals (No. 4) Order, 1939, dated October 23, 1939.

This Order amends the Schedule of maximum prices attached to the Non-Ferrous Metals (No. 2) Order, 1939, (i) by removing therefrom the following materials—viz., zinc sulphide, lithopone, and zinc dust; (ii) by increasing the maximum prices for zinc oxide (Red Seal quality), zinc sheets and zinc boiler plates—and adjusting the price of hard spelter and dross for delivery on an "ex works" basis; and (iii) by fixing for the first time maximum prices for various forms of non-ferrous scrap.

Copies of the Order may be purchased directly from H.M. Stationery Office at York House, Kingsway, London, W.C. 2, or through any bookseller.

Wrought Aluminium and Aluminium Alloys for Aircraft Purposes

THE following new and revised British Standard Specifications for Aircraft Purposes have just been issued by the British Standards Institution :—

　　6 L.1. Aluminium alloy bars, extruded sections and forgings (not greater than 3 in. diameter or minor sectional dimension).
　　4 L.25. Aluminium alloy forgings (including pistons and cylinder heads).
　　3 L.31. 99% aluminium notched bars and ingots for remelting.
　　2 L.37. Aluminium alloy rivets.
　　2 L.39. Aluminium alloy bars and forgings (greater than 3 in. diameter or width across flats or minor sectional dimension).
　　2 L.40. Aluminium bars, extruded sections and forgings (not greater than 3 in. diameter or minor sectional dimension).
　　2 L.42. Aluminium alloy forgings (including pistons and cylinder heads).
　　L.44. Soft aluminium alloy extruded bars and sections (not greater than 3 in. diameter or minor sectional dimension).
　　L.45. Aluminium alloy bars and forgings (greater than 3 in. diameter or width across flats or minor sectional dimension).
　　L.46. Soft aluminium alloy sheets and coils.
　　L.47. Aluminium coated aluminium alloy sheets and coils.

The principal modifications to the revised specifications are as follows :—

In Specifications 6 L.1 and 2 L.40 a reduction of 1 ton per sq. in. has been allowed in the proof and ultimate tensile stresses specified for extruded sections not greater than ⅜ in. in thickness. Forgings are represented by a test sample of not less than 1⅛ in. thickness instead of being represented by a test sample of the ruling thickness of the forging.

In Specification 2 L.39, which is for bars and forgings greater than 3 in. diameter or minor sectional dimension, bars and billets for forging as well as forgings are represented by a test sample not less than 1⅛ in. diameter, and this test sample must give the tensile properties specified in 6 L.1. Bars for machining in 2 L.39 are divided in two sections—viz., bars over 3 in. up to and including 6 in. diameter, and bars over 6 in. up to and including 8 in. diameter or minor sectional dimension. The proof and ultimate tensile stresses of the bars 3 in. to 6 in. diameter are each 3 tons per sq. in. lower than the values specified in 6 L.1, and the corresponding values for bars 6 in. to 8 in. diameter are respectively 4·5 and 5 tons lower than are specified in 6 L.1.

L.45 is a new specification covering the 2 L.40 material for bars and forgings in sizes greater than 3 in. diameter or minor sectional dimension. Like 2 L.39, L.45 specifies lower values for bars for machining over 3 in. For bars 3 in. to 6 in. diameter, the proof and ultimate tensile stresses are each 2 tons per sq. in. lower than in 2 L.40, and for bars over 6 in. to 8 in. diameter 4 tons per sq. in. lower.

L.44 is a new specification for soft aluminium alloy extruded bars and sections having maximum dimensions of 3 in. diameter or width across flats. For this material an ultimate tensile stress of not less than 11 tons per sq. in. is specified.

Specification 4 L.25 replaces Specifications 3 L.25 and L.43 for " Y " alloy bars and forgings. The bars and billets for forging are limited to 5 in. diameter or width across flats. No alteration has been made to the tensile strength figures formerly specified.

In Specification 2 L.42 the tensile strength figures remain as previously specified.

In all the specifications the procedure for the selection and preparation of the test samples has been modified and the term " cast " as applied to the various melting processes employed has been defined.

L.46 is a new B.S. Specification for soft aluminium alloy sheets and coils having a tensile strength of not less than 11 tons per sq. in., and replaces the Air Ministry Material Specifications D.T.D. 180A, 209A, 278 and 292.

L.47 for aluminium coated aluminium alloy sheets and coils is also a new B.S. Specification replacing the Air Ministry Material Specifications D.T.D. 342 and 351. The specification covers the requirements for sheets and coils in the softened, quenched, and quenched and aged conditions.

In the revised Specification 2 L.37 provision has been made for tubes as well as for rods and wires for rivets.

In Specification 2 L.31 for 99% aluminium notched bars and ingots for remelting purposes a limit has been set on the amount of copper and zinc in place of a limit on metallic impurities generally. The term " cast " as applied to, notched bars and ingots has been defined and the selection of samples for chemical analysis has been reduced to 1%.

Copies of these specifications may be had from the British Standards Institution 28 Victoria Street London, S.W. 1, price 1s. each (1s. 2d. post free).

A.S.T.M Spring Meeting

THE technical feature of the 1940 Spring Meeting of the American Society for Testing Materials, held at Detroit, U.S.A., on March 6, was a symposium on new materials in transportation, comprising six papers, two of which have special metallurgical interest since one deals with exhaust valve materials for internal combustion engines and the second gives a selection and application of automotive steels. The paper on valve materials, by Messrs. S. D. Heron, O. E. Harder, and R. M. Nestor, outlines the chemical and physical properties desirable and their significance and describes media which cause attack or corrosion. Methods of testing are covered and effects of operating temperatures.

The second paper, by Messrs. A. L. Boegehold, W. H. Graves, and E. W. Upham, discusses the steel requirements of a number of motor-car parts together with the considerations applied in deciding the choice of steel for these parts. Typical parts such as piston pins, camshafts and gears are discussed giving the steels actually used and pointing out how service and manufacturing requirements such as strength, wear resistance, machinability and costs affect the final selection. The application and use of hardenability as a property of steel is discussed as it affects the selection of steels for motor-car parts. The need for a standard hardenability test is emphasised. For this purpose additional information about cooling ratio is required and this paper discusses the procurement and use of such information.

Magnesium Metal from Seawater

MAGNESIUM is generally produced in Italy by electrolysis of a mixture of dehydrated magnesium chloride and alkali chloride, the process coming to a standstill when the magnesium chloride content of the bath falls to a very low level. A fresh supply of magnesium chloride for the electrolyte can be derived from seawater and a process based on this principle has been developed by the Montecatini Company.

Under certain conditions the treatment of seawater with lime salts gives a precipitate of magnesium hydroxide which is then washed and carbonated to give crystalline magnesium carbonate. The latter is reacted under pressure with carbon dioxide and sodium chloride when magnesium chloride is formed and remains in solution while the sodium bicarbonate formed at the same time is removed by filtration and may be worked up to caustic soda.

The extremely pure magnesium chloride solution is mixed with the residual potassium chloride from the empoverished electrolyte to form a mixture which is dehydrated to carnallite. Electrolysis of the latter yields magnesium metal, potassium chloride and chlorine.

Business Notes and News

British Overseas Trade

British overseas trade in January shows a large increase in imports, the value of which exceeded £100 million for the first time since January, 1930. At nearly £105 million the import trade exceeded the December total by over £18½ million and was £29½ million higher than in January, 1939. Much of the increased values registered were due to higher prices, but no indication is given in the Board of Trade returns how these affect the volume of trade.

Exports for the month at £41 million were up by about £1 million on those of December and £1½ million on those of January, 1939. Noteworthy increases are shown in the value of such important exports as chemicals, iron and steel, and coal, but notable declines are recorded for machinery, and in the vehicles group, which includes locomotives, ships, and aircraft, as well as motor cars. Re-export trade for the month at £3,600,000, showed an increase over December total of more than £1,100,000, but was well below the total in January, 1939.

It will be noted that the gap between imports and exports is very wide and only by exploiting all the knowledge and facilities existing in trade and industry, and by effective Government co-operation, can the closing of this gap be successfully achieved.

Arc Welding in Aeroplane Construction

The Boeing Aircraft Corporation are making considerable use of electric arc welding in the construction of aeroplanes. Arc welding is used in the construction of the engine mount for such planes as the "Stratoliner" and for the "Flying Fortress" shown in the accompanying illustration. Arc welding is also used in the construction of special frame of tubular components which is used for picking up fuselages for transporting purposes by overhead crane. This firm employed the shielded arc process of electric welding and it is noteworthy that the Boeing "Clipper," now in around-the-world trans-oceanic service, is another example in which this form of jointing is employed.

The American "Flying Fortress."

Research Laboratory for Powder Metallurgy

Work on powder metallurgy has made great progress in recent years and it is significant of the importance of this development that an increasing amount of work is being devoted to this branch of metallurgy. It is noteworthy in this connection, that American Electro Metal Corporation is at present equipping a modern research laboratory to be used especially for powder metallurgy. The laboratory, with an approximate floor space of sixteen thousand square feet, is located at 320, Yonkers Avenue, Yonkers, New York, U.S.A.

The laboratory will provide departments for powder manufacture, milling, pressing, sintering, metal working, as well as mechanical, chemical, metallographical, spectrographical and X-ray testing. Complete machine tool equipment will also be available. The work programme will be a continuation of previous research work carried out by this company's president, Dr. Paul Schwarzkopf.

Hospitals Exhibition

The 30th Annual Hospitals Exhibition will be held at the Royal Horticultural Hall, London, from April 8 to 12, inclusive, where hospital equipment and appliances of all description will be on view and visitors will have an opportunity of seeing the extent to which stainless steel is now applied in this field.

Noteworthy will be the display of Firth-Vickers Stainless Steels Ltd. which includes a wide range of "Staybrite" steel hospital utensils and equipment comprising trolleys, sterilisers, bowls of all descriptions, dental instruments, stainless steel dentures, instrument trays and a wide range of surgical instruments. Stainless steels in this range are obtainable with a very highly polished surface, free from porosity, and therefore, offer no lodgment for bacteria. They are of pleasing appearance, and being both tough and ductile, articles made from it can be hammered flat without breaking, and are, therefore, indestructible in service.

Aluminium Control

The Ministry of Supply have made arrangements with the British Aluminium Company and the Aluminium Company of Canada for substantial increases in the output of aluminium in the United Kingdom and Canada. In Canada, for instance, the increase in output is sufficient to make the total capacity of that country alone almost equal to that of Germany. The two companies have, moreover, undertaken to co-operate with the Ministry of Supply in developing any further increases in capacity which may be required.

The Ministry have also purchased the entire output of the British Aluminium Company for 1940 and of the Aluminium Company of Canada for the remainder of 1940 and the whole of 1941, less only that required for consumption in Canada and for fulfilling certain pre-war commitments. Basic prices approximately equal to those current in the United Kingdom and Canada before the war have been agreed.

Iron and Steel Control Order

The Minister of Supply has made the Iron and Steel (No. 7) (Scrap) Order, 1940, which took effect as from March 5. It fixes new prices for iron and steel scrap and supersedes the Control of Iron and Steel (No. 5) (Scrap) Order, 1939 (S.R. & O., 1939, No. 1626).

The effect of the Order is to increase the main range of maximum prices of iron and steel scrap by from 5s. to 10s. per ton. Adjustments to meet changing conditions have led to larger increases in a few cases.

In substance the scope of the Order remains unchanged but there have been certain additions to the specifications of the material covered by the maximum price provisions.

The Direction (No. 1) under the Order issued therewith repeats the provisions of the similar Direction under the previous Order exempting the sale and purchase of scrap from the requirement of licence except for certain types.

Copies of the Order may be purchased from H.M. Stationery Office, York House, Kingsway, London, W.C. 2, etc., or through any bookseller.

Machinery, Plant and Appliances

Cases have come to the notice of the Import Licensing Department in which importers have placed orders for machinery, plant and appliances to be constructed abroad without first ascertaining that a licence for the importation of the goods will be issued.

Importers are accordingly warned that no goods of this class can now be imported without a licence unless they are consigned direct to a Government Department, and the fact that an order has already been placed will not influence the Department in the direction of granting a licence which they would otherwise refuse.

Accordingly, importers are advised not to place any orders abroad for machinery, plant or appliances until they have either obtained an import licence or ascertained definitely that a licence will be granted or that no licence is required. Where it is expected that some considerable time will elapse between the placing of the order and the delivery of the goods, arrangements can be made, if necessary, to extend the period of validity of any licence that may be issued beyond the usual period of three months.

MARKET PRICES

ALUMINIUM.

Ingots £110 0 0

ANTIMONY.

	£	s	d
English	95	0	0
Foreign	76	10	0

BRASS.

		£	s	d
Solid Drawn Tubes	lb.	£0	1	1½
Brazed Tubes	,,	0	1	3½
Rods Drawn	,,	0	0	11½
Wire	,,	0	0	10½
*Extruded Brass Bars	,,	0	0	7½

COPPER.

		£	s	d
Standard Cash		£61	10	0
Electrolytic		62	0	0
Best Selected		61	10	0
Tough		6?	5	0
Sheets		96	10	0
Wire Bars		65	10	0
Ingot Bars		65	10	0
Solid Drawn Tubes	lb.	0	1	2¾
Brazed Tubes	,,	0	1	2¾

FERRO ALLOYS.

		£	s	d
‡Tungsten Metal ° Powder, nominal	lb.	£0	5	2½
‡Ferro Tungsten ° nominal	,,	0	5	1
Ferro Molybdenum °	,,		5	7

Ferro Chrome, 60-70% Chr.
Basis 60% Chr. 2-ton lots or up.

		£	s	d
2-4% Carbon, scale 15/- per unit	ton	45	5	0
4-6% Carbon, scale 12/6 per unit	,,	39	10	0
6-8% Carbon, scale 12/6 per unit	,,	38	10	0
8-10% Carbon, scale 12/6 per unit	,,	38	10	0

§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch.

		£	s	d
Guar. max. 2% Carbon, scale 18/6 per unit	,,	58	0	0
Guar. max. 1% Carbon, scale 19/6 per unit	,,	60	0	0
§Guar. max. 0·5% Carbon, scale 20/- per unit	,,	71	0	0
‡Manganese Metal 97-98% Mn	lb.	1/5½	to	1/9
‡Metallic Chromium	,,	3/2½	to	3/7½
§Ferro-Vanadium 50-55%	,,	0	15	6
§Spiegel, 18-20%	ton	12	2	6

Ferro Silicon—

		£	s	d
Basis 10%, scale 3/- per unit nominal	ton	15	0	0
20/30% basis 25%, scale 3/6 per unit	,,	17	10	0
45/50% basis 45%, scale 5/- per unit	,,	19	0	0
70/80% basis 75%, scale 7/- per unit	,,	29	10	0
90/95% basis 90%, scale 10/- per unit	,,	40	0	0
§Silico Manganese 65/75% Mn, basis 65% Mn	,,	26	0	0
§Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	7½
Ferro Phosphorus, 20-25%	ton	35	0	0
§Ferro-Molybdenum, Molyte	lb.	0	5	7
§Calcium Molybdate	,,	?	5	5

FUELS.

Foundry Coke—

	£	s	d
S. Wales	£2	0	6
Scotland	1	17	6
Durham	1	17	0

Furnace Coke—

	£	s	d
Scotland	1	9	0
S. Wales	1	9	0
Durham	1	11	8

GUN METAL.

		£	s	d
*Admiralty Gunmetal Ingots (88 : 10 : 2)		£91	0	0
*Commercial Ingots		76	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards— chill cast	lb.	0	1	1½
*Cored Bars	,,	0	1	3½

MANUFACTURED IRON.

	£	s	d
Scotland—			
Crown Bars	£12	17	6
N.E. Coast—			
Rivets	—		
Bars	11	17	6
Crown Bars	12	17	6
Lancashire—			
Crown Bars	12	17	6
Hoops	13	11	0
Midlands—			
Crown Bars	12	17	6
Marked Bars	15	15	0
Unmarked Bars	—		
Nut and Bolt Bars	11	7	6
Strip	14	5	0
S. Yorks.—			
Bars	11	17	6
Hoops	14	12	6

PHOSPHOR BRONZE.

		£	s	d
*Bars, "Tank" brand, 1 in. dia. and upwards—chill cast	lb.	£0	1	1½
*Cored Bars	,,	0	1	3½
†Strip	,,	0	1	1½
†Sheet to 10 W.G.	,,	0	1	1½
†Wire	,,	0	1	3½
†Rods	,,	0	1	1½
†Tubes	,,	0	1	9
†Castings	,,	0	1	3

†10% Phos. Cop. £30 above B.S.
†15% Phos. Cop. £35 above B.S.
†Phos. Tin (5%) £30 above English Ingots.

PIG IRON.

	£	s	d
Scotland—			
Hæmatite M/Nos.	£6	7	6
Foundry No. 1	5	15	0
,, No. 3	5	12	6
N.E. Coast—			
Hæmatite No. 1	6	7	6
Foundry No. 1	5	11	0
,, No. 3	5	11	0
,, No. 4	5	4	6
Silicon Iron	—		
Forge	—		
Midlands—			
N. Staffs. Forge No. 4	5	9	6
,, Foundry No. 3	5	13	0
Northants—			
Foundry No. 1	5	11	6
Forge No. 4	—		
Foundry No. 3	5	10	6
Derbyshire Forge	5	0	0
,, Foundry No. 1	5	13	0
,, Foundry No. 3	5	13	0
West Coast Hæmatite	6	7	6
East ,, ,,	6	7	6

SWEDISH CHARCOAL IRON AND STEEL.

Pig Iron—

	Kr
Single welded acid steel billets, ·50% C and up	Kr. 390
Acid steel wire rods, ·50% C and up	Kr. 450 to 495
Rolled charcoal iron bars	Kr. 510

All Swedish Kronor per British ton f.o.b. Swedish port.

SCRAP METAL.

	£	s	d
Copper, Clean	£56	10	0
,, Braziery	53	10	0
,, Wire	55	10	0
Brass	47	0	0
Gun Metal	72	0	0
Zinc	10	0	0
Aluminium Cuttings	72	0	0
Lead	11	10	0
Heavy Steel—			
S. Wales	3	12	3
Scotland	3	9	0
Cleveland	3	11	0
Cast Iron—			
Midlands	3	17	0
S. Wales	3	17	0
Cleveland	3	16	6
Steel Turnings—			
Cleveland	2	12	0
Midlands	2	5	3
Cast Iron Borings—			
Cleveland	2	5	0
Scotland	2	5	0

SPELTER.

	£	s	d
G.O.B. Official	£25	15	0
Hard	—		
English	26	10	0
Empire	26	10	0
Re-melted	16	10	0

STEEL.

	£	s	d
Ship, Bridge and Tank Plates—			
Scotland	£12	13	0
North-East Coast	12	13	0
Midlands	12	13	0
Boiler Plates (Land) Scotland	13	10	6
,, ,, (Marine) ,,	—		
,, ,, (Land) N.E. Coast	13	10	6
,, ,, (Marine) ,,	—		
Angles, Scotland	12	8	0
,, North-East Coast	12	8	0
,, Midlands	12	8	0
Joists	12	8	0
Heavy Rails	11	3	0
Fishplates	15	10	0
Light Rails	13	6	6
Sheffield—			
Siemens Acid Billets	12	17	6
Hard Basic	11	7	6
Medium Basic	11	5	0
Soft Basic	11	0	0
Hoops	14	11	0
Manchester—			
Hoops	14	11	0
Scotland, Sheets 24 B.G.	17	10	0

¶HIGH-SPEED TOOL STEEL.

		£	s	d
Finished Bars 14% Tungsten	lb.	£0	3	0
Finished Bars 18% Tungsten	,,	0	3	10

Extras :

		£	s	d
Round and Squares, ½ in. to ¼ in.	,,	0	0	3
Under ¼ in. to ⅛ in.	,,	0	1	0
Round and Squares, 3 in.	,,	0	0	4
Flats under 1 in. × ½ in.	,,	0	0	3
,, ½ in. × ¼ in.	,,	0	1	0

TIN.

	£	s	d
Standard cash	£252	15	0
English	252	15	0
Tin Plates I.C. 20 × 14 box	£1	12	0

ZINC.

	£	s	d
English Sheets	£39	2	6
Zinc Boiler Plates	37	2	6
Battery Plates	—		
Boiler Plates	—		

LEAD.

	£	s	d
Soft Foreign	£25	0	0
Empire	25	0	0

---

*McKechnie Brothers, Ltd., Mar. 13. † C. Clifford & Sons, Ltd., Mar. 13. ‡ Murex Limited., Mar. 13.
Subject to Market fluctuations. Buyers are advised to send inquiries for current prices when about to place order.

§ Prices ex warehouse, Mar. 13. ¶ The prices fluctuate with the price of Tungsten.

FILE THIS IN YOUR CABINET

You will then be able to refer to contents of previous issues easily.

Contents.

METALLURGIA.   For MARCH, 1940.